

**Appendix P**  
**Dry Cargo Residue Discharge Analysis Using**  
**Mathematical Simulations**

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## 2 3 Dry Cargo Residue Discharge Analysis for the U.S. 4 Coast Guard

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### 5 Executive Summary

6 The U.S. Coast Guard is conducting a study of dry cargo residue (DCR) sweeping  
7 discharges from bulk cargo ships on the Great Lakes to understand the potential  
8 environmental influence of the discharges and to support policy development on the issue.  
9 This memorandum documents an analysis of potential water quality and sediment impact  
10 of the DCR. The analysis employed focused mathematical modeling to simulate water  
11 quality impacts and deposition rates and used those results to make conclusions regarding  
12 water quality associated with the sweeping and the buildup of sweeping material over time.

13 Liquid and solid samples were collected from the decks and sumps of eight bulk dry cargo  
14 vessels (CH2M Hill February 2007; USCG Dry Cargo Sweepings Scientific Investigation:  
15 Sweepings Characterization – Chemical Analyses). Analytical results were compared to  
16 chronic and acute water quality criteria obtained from the Great Lakes Initiative and the  
17 U.S. Environmental Protection Agency (USEPA) for the protection of aquatic life and human  
18 health. This comparison did not take into account the dilution that would occur during  
19 sweepings discharges. This was a useful comparison from a screening perspective, however,  
20 because discharge parameters that meet criteria even without consideration of applicable  
21 dilution can be regarded as parameters that do not require further impact assessment. There  
22 are only three instances in which chronic water quality criteria were exceeded in undiluted  
23 samples by more than a factor of 10, and the highest exceedance of acute water quality  
24 criteria was by a factor of 1.9.

25 Solids sampled from the sumps and decks of the vessels demonstrated that limestone and  
26 taconite solids did not exceed any sediment criteria. Again, the sample results did not take  
27 into account dilution, dispersion and attenuation that would occur as the solids integrate into  
28 lake bottom sediments. The comparison of undiluted samples to sediment criteria again  
29 provides a defensible basis to screen out parameters that do not require further assessment.  
30 Coal DCR sweepings collected from ship decks generally exceeded criteria for polycyclic  
31 aromatic hydrocarbons (PAHs) such as naphthalene and pyrene by a factor of up to 5 in some  
32 individual undiluted samples. Only one vessel had sump solids that exceeded sediment  
33 criteria. The sump solids collected from that ship showed elevated levels of metals. The

exceedance of metals criteria on this single ship seems to be the result of incorporation of foreign metallic materials, such as wire or metal shavings, because none of the DCR materials themselves exceeded any metals criterion. More extensive sampling is required to determine the true nature of DCR on Great Lakes sediment. However, preliminary results indicate that most of the undiluted samples collected meet most water quality and sediment criteria.

DCR sweepings data obtained from log books from 31 ships were analyzed. The data represent 2,777 DCR discharges during the 10-month period of April 2004 to January 2005 (USCG, 2005). The sweepings were mainly coal, limestone, and taconite and occurred in Lake Superior, Lake Michigan, and Lake Erie. The discharge data show that the typical DCR sweeping discharge is a relatively small amount of material distributed over a relatively large section of the lake (average length of discharge: 54 miles). The median discharged mass was 175 pounds, and the median distance over which the discharge occurred was 43 miles. An estimation based on collected data determined that DCR accounts for only 0.0006% of the total amount of cargo transported through the Great Lakes (Potomac Management Group 2003).

A review of computer modeling software packages determined that few modeling applications would apply to DCR on the Great Lakes. To analyze water quality impacts, a Simple Dilution Model was used. None of the evaluated modeling programs was applicable to the sediment quality modeling; therefore, a spreadsheet model was developed specifically for this analysis.

The Simple Dilution Model used to estimate dilution of DCR sweepings water discharges was created to predict dilution of discharged wastewater from cruise ships in Alaskan seas (Loehr et al. 2003). The model proved to be the most useful and applicable of all those evaluated. It demonstrates that dilution factors from 27,000 up to 1,020,000 can be expected for DCR from moving bulk cargo vessels on the Great Lakes. These dilution factors are due to the large displacement of water and jetting of large propellers, which creates a wide swath of turbulence and mixing behind moving ships. The dilution factors are achieved within 15 minutes of discharge (Alaska DEC 2001), ensuring that the discharge of DCR sweepings has an insignificant impact on water quality.

Naphthalene (present in coal sweepings) was the chemical parameter of highest average concentration in the discharged solids. Using conservative assumptions, it was found that if all the coal discharged through sweepings to Lake Superior in a given year is spread uniformly over a 10-mile by 1,230-feet (375-meter) area, sediment criteria will be met with a safety factor through natural sedimentation processes only. If natural sedimentation is considered negligible and dilution is assumed to occur through mixing with the top 2 inches of existing sediment, coal discharged over 100 years evenly spread over an area of 10 miles by 492-feet (150-meters) meets sediment criteria with a safety factor. In reality, coal DCR sweeping discharges are spread over an area much larger than 10-miles by 1,230-feet (375-meters), indicating no significant impact on sediments.

Because of the small mass of the discharges and the relatively benign nature of the material, there is no significant impact to the lake sediments from an evenly dispersed discharge of DCR sweepings. Even the largest discharges (92 pounds/mile) are required to be spread out over a width of only 6.6 feet (2 meters) in order to be diluted to meet sediment criteria by natural sedimentation. In reality, coal DCR discharged from a moving cargo vessel will be

spread out much more than 6.6 feet (2 meters) because of wake turbulence. Large cargo vessels can be up to 98 feet (30 meters) in width, and the turbulent zones behind the ships are about 2.5 times greater than the ship width (Loehr et al. 2003). This analysis also assumes conservative sedimentation rates for the central basin of Lake Superior and a safety factor of 10.

The single densest discharge of coal was chosen to be the 99th percentile obtained from the 2004 database (USCG, 2005). Only 1 percent of discharges in this database were denser than 92 pounds/mile. The 99th percentile discharge must be spread over a width of 6.9 feet (2.1 meters) in order to be diluted by natural sedimentation to meet sediment criteria with a safety factor. The coal is spread over a wider area due to mixing; therefore, the DCR meet sediment criteria by either natural sedimentation or mixing with the top two inches of sediment.

An analysis of the volume of historical DCR sweepings using sonar data (Mackey, S. D. 2006) determined that some of the DCR sweepings sonar images cover a relatively large area and are not likely the result of current typical DCR sweepings. The loading and unloading of cargo has improved in recent times, and the amount of DCR sweepings that is swept overboard has been reduced from historical levels. DCR is typically discharged in very small amounts over vast areas of the lake. The 99th percentile discharge is only 92 lbs/mile (see DCR discharge Data). This would equate to about 1 1/2 five gallon buckets of coal DCR spread over a length of 1 mile. The coal would likely be spread out at least one ship width (>68') as the turbulent mixing zone is considered to be 2.5 times the width of the vessel (Loehr et al. 2003). The largest current recorded DCR represent relatively small amounts of material discharged over vast areas, therefore, it is assumed that most of the deposits observed during the sidescan sonar study are not typical of current DCR practices. However, further research and field verification are required to determine the origin of deposits observed during the sidescan sonar study.

Conservative assumptions were employed throughout the water and sediment quality analyses. The water and sediment analyses confirm that DCR discharges are diluted to the point that water and sediment quality criteria are met and no significant adverse impacts on water or sediment quality are expected.

## Introduction

The Great Lakes dry bulk carrier industry transports more than 150 million tons of dry bulk cargo on the Great Lakes each year. Dry cargo includes iron, coal, limestone, grain, salt, gypsum and other materials; however, iron, coal, and limestone account for most of the transported material. A small amount of material is spilled on the decks and in the below-deck conveyor tunnels of the cargo vessels during loading and unloading operations. Historically, nonhazardous, nontoxic spilled material is discharged into the lake to eliminate unsafe conditions onboard. Material spilled on the ship deck is washed overboard after each unloading operation, and spilled material in the tunnels is washed every two to three trips. The tunnel material is collected in a sump that discharges out the side of the ship. About 0.006 percent of the total transported cargo material is discharged to the Great Lakes as DCR sweepings during vessel washdown operations. In 2001, 165 million tons of cargo was

transported on the Great Lakes, and 494 tons of cargo was discharged as DCR sweepings (Potomac Management Group 2003).

The discharge of DCR sweepings on the Great Lakes is governed by the Interim Enforcement Policy (IEP), which is mandated to expire on September 30, 2008 (USCG, 2005). The U.S. Coast Guard is conducting a study of DCR discharges from bulk cargo ships on the Great Lakes to understand the potential environmental influence of the discharge and to support a policy development on the issue. This memorandum documents an analysis of potential water quality and sediment impact of the DCR discharges. The objective of the DCR discharge analysis was to use focused mathematical modeling to simulate water and sediment quality impacts associated with the sweeping.

The type of mathematical model most appropriate for the analysis depends upon whether the DCR sweepings can significantly affect the water column water quality, the substrate, water quality through chemical reaction, or a combination.

The number of possible combinations of material, location, substrate type, etc., is extensive. This study prioritized the analysis based upon the comprehensive information gathered on DCR sweepings locations, materials, etc. during previous tasks. Following this approach focused the modeling analysis in areas where actual impacts may be occurring.

Information gained from prior analysis guided model selection and model inputs. Efforts previously undertaken include conducting a sophisticated sonar study in several study areas on Lakes Superior, Michigan, and Erie (Mackey, S. D. 2006); collecting and characterizing extensive samples of deck DCR sweepings and sump slurries of coal, limestone, and taconite (CH2M Hill February 2007; USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization—Chemical Analyses Technical Memorandum); and collection of toxicological and nutrient enrichment data from DCR sweepings samples (CH2M Hill February 2007 USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization—Toxicological Analyses Technical Memorandum; USCG Dry Cargo Sweepings Scientific Investigation: Biological Characterization—Nutrient Enrichment Technical Memorandum). The information gained from these efforts was considered and included in the modeling analysis as appropriate.

## Modeling Objective

The modeling used chemical analysis, DCR sweepings grain size distribution, physical lake data, and DCR discharge data in conjunction with modeling software and calculation approaches to predict chemical concentrations in the water column in comparison to water quality standards. The modeling task also determined information on coverage and buildup of sweeping material over time to determine effects on sediment quality.

## Evaluation of Modeling Software

Liquid and solids samples were collected from the decks and sumps of eight bulk dry cargo vessels. Analytical results were compared to chronic and acute water quality criteria determined by the Great Lakes Initiative and the USEPA criterion for the protection of aquatic life and human health concerns. The DCR sweepings characterization chemical analysis data (CH2M Hill February 2007; USCG Dry Cargo Sweepings Scientific

Investigation: Sweepings Characterization – Chemical Analyses Technical Memorandum) show that there are few chemical parameters for which the sump slurries exceed acute water quality benchmark criteria. Modeling can determine the extent of mixing and estimate chemical concentrations over time in the affected water column.

The effect that mixing has upon the chemical concentration depends upon the sweeping chemical concentrations in the discharge, background concentrations in the receiving water, and a host of other factors.

There are mathematical models for modeling plume discharges and for modeling ship wakes, but the two models have not been combined. There is sparse documentation directed specifically at determining dilution of discharges from moving ships (CH2M Hill February 2007; USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Toxicological Analyses). However, one study generated a Simple Dilution Model and validated the model in order to determine dilution of wastewater discharged from moving cruise ships in Alaskan seas. Table 1 lists the nine models evaluated for potential application for modeling DCR sweepings.

TABLE 1  
Discharge Models Evaluated for Potential Application for Modeling of DCR Sweeping Discharge

Model	Contact	Purpose	Status
Simple Dilution Model	See Loehr et al. 2003	Evaluate dilution of wastewater discharges from cruise ships in Alaskan waters.	Published 2003
Visual Plumes	USEPA	Assists in the preparation of mixing zone analyses, total maximum daily loads, and other water quality applications.	Available from USEPA
Cormix	USEPA	Provides documented water quality modeling, NPDES regulatory decision support, visualization of regulatory mixing zones, and tools for outfall specification and design.	Available from USEPA
STFATE (Short Term Fate)	USACE	Short term fate of discrete disposal of dredged material, water column impact, and deposition	Available from USACE
CDFATE (Continuous Disposal Fate)	USACE	Water column impact due to continuous disposal of dredged material; Also able to model discrete dumps	Available from USACE
OOC (Offshore Operators' Committee)	Offshore Operators' Committee	Water column impact and deposition due to offshore drilling	Not Available
CD-Cormix	USEPA	Extends the CORMIX expert system to water quality prediction from continuous dredge disposal sources; DOS based program	Available from USEPA and USACE
D-Cormix	USEPA	Extends the CORMIX expert system to water quality prediction from continuous dredge disposal sources; Windows Based Program	Under development in cooperation with USEPA and USACE
MDFATE (Multiple Disposal Fate)	USACE	Models bathymetry changes due to multiple disposals in a specific area	Available from USACE

A Simple Dilution Model was published in OCEANS 2003 Proceedings (Loehr et al. 2003). The model was developed by an independent Science Advisory Panel to assist the Alaska

Department of Environmental Conservation in evaluating the effects of wastewater discharges from cruise ships in Alaskan waters.

Visual Plumes (Frick et al.2001) is a modeling program that simulates surface water jets and plumes in order to determine water quality impacts due to a liquid discharge. Cormix (Jirka et al.1996) is able to model submerged single-port and multiport diffuser discharges as well as surface discharge sources and is useful for modeling the impact of liquid discharges on receiving waters (i.e. treated wastewater outfall into a river). These two models are designed specifically for liquid discharges.

Models created to simulate discharged liquid are insufficient to model the discharge of DCR sweepings slurries. No models exist to predict the dilution and dispersion of discharged DCR sweepings slurries. However, models have been created to simulate the dilution and dispersion of dredged material at open water dredged material disposal sites as well as offshore drilling sites (Table 1).

The United States Army Corps of Engineers (USACE) maintains a suite of dredged material disposal modeling software in order to predict many aspects of dredged material disposal including water quality impacts, sediment accumulation, and release of chemical parameters from disposed material in sediments. This modeling software suite is known as ADDAMS (Automated Dredging and Disposal Alternatives Modeling System). STFATE (U.S. EPA 1995), CDFATE (Chase, D. 1994), and MDFATE (Moritz 1994) are components of ADDAMS.

A modeling program known as the Offshore Operators Committee Model (OOC model) (MBC 1983) is able to simulate a variety of offshore oil field discharges characterized by unsteady, three dimensional behavior. Discharges are assumed to originate from a single port outfall. The OOC model predicts the distribution of discharged materials in the water column and the deposition of materials on the sea floor. This model can be applied to mud, cuttings and produced water discharges. The model was developed by Brandsma and Sauer (MBC 1983) under sponsorship of the Offshore Operators' Committee (OOC). The model has been used by government and industry to estimate the likely behavior and fate of drilling mud and cuttings discharged in the marine environment. However, the model is not publicly available or available for purchase. OOC modeling work must be performed by Brandsma Engineering of Durango, CO.

Additionally, CD-Cormix (Jirka et al.1996) is available to model continuous dredge disposals. This is a DOS-based program that uses Cormix methodology to predict water column impacts resulting from continuous dredged material disposal. CD-Cormix is fairly difficult to use because it is available only in DOS format, and the programming does not allow easy transition between modules. However, MixZon Inc. is developing D-Cormix (Doneker & Jirka 1997) in cooperation with the USACE and the USEPA. D-Cormix is a Windows-based modeling program that extends the CORMIX system to water quality prediction from continuous dredge disposal sources. It models water column characteristics resulting from sources of suspended sediment in continuous pipeline dredging operations often referred to as "flow lane" or "in-water" disposal. An evaluation version of this program was tentatively scheduled to be released online in March 2007, but was not available at the time of printing this memo.

## Model Selection

Important factors considered in the model screening process were:

- Applicability of Model to DCR sweepings Scenarios – High scores were given to models that were created to analyze scenarios similar to the DCR discharge scenarios.
- Level of Detail of Output Concentrations – Models that are able to report exact concentrations of chemical parameters and solids at any point in the water column at any time received the highest score.
- Data Input Needs – High scores were given to programs that required minimal data input
- Solids Input Capability – High scores were given to programs that allow entry of grain size distribution and solids content of the discharged material; higher scores were given for the number of solids fractions allowed in the program
- Ease of Use – Models that are designed for the Microsoft Windows® Operating System and have sufficient documentation and on screen explanations received high scores

MDFATE was not considered in the model selection because it does not have the ability to simulate chemical parameter concentrations in the water column. MDFATE is useful only to predict deposition. The D-Cormix and OOC models were not considered in the model selection because these models are not currently available.

The highest scoring models from the screening process were the Simple Dilution Model and STFATE (Table 2). The Simple Dilution Model scored highly because of its applicability to the DCR discharge problem. The Simple Dilution Model is likely the most accurate of all models in predicting near field mixing behind a moving cargo vessel. The Simple Dilution Model also scored highly in ease of use and data input needs because it is a simple equation, therefore no specialized software is necessary. The main disadvantage of the Simple Dilution Model is that the output is very limited. The only output from this model is an order of magnitude estimated dilution factor. This model cannot predict concentrations at various points in the water column over time. STFATE, however, is much more sophisticated. This Windows-based software was created to model a dredge dump from a split hull barge. STFATE can predict chemical and solids concentrations at any point in the water column. STFATE is also able to generate graphics showing concentration contours at various depths and time as well as three dimensional bathymetric graphs of accumulated sediment on the lake bottom.

TABLE 2  
Model Comparison

Scale (1–5)	Applicability of Model to DCR Sweepings Scenarios	Level of Detail of Output Concentrations	Data Input Needs	Model Ease of Use	Solids Input Capability	Weighted Score
Simple Dilution Model	5	2	5	5	0	3.9
STFATE	3	5	2	2	4	3.1
CDFATE	1	3	3	3	4	2.5
CD-Cormix	2	5	3	1	4	2.8
Visual Plumes	1	5	3	3	0	2.5

**TABLE 2**  
Model Comparison

Scale (1-5)	Applicability of Model to DCR Sweepings Scenarios	Level of Detail of Output Concentrations	Data Input Needs	Model Ease of Use	Solids Input Capability	Weighted Score
Cormix	1	5	3	3	0	2.5
Weighting Factor	0.3	0.2	0.2	0.2	0.1	1

Applicability of the model to DCR discharge scenarios was given the highest weighting factor due to its importance in model selection. The next highest weighting factors were assigned based upon data input, data output, and model operation. The lowest weighting factor was assigned to capability of including solids in the input because the DCR consists of both solids and liquids.

Although STFATE is more powerful than the Simple Dilution Model, it is also much more difficult to use and to understand and is less applicable to the DCR discharge scenarios than is the Simple Dilution Model. STFATE was designed to model large dumps (400 to 6,000 yd<sup>3</sup>) of dredged material discharged below the water surface from the bottom of a split hull barge. In contrast, the DCR discharges are relatively small dumps (< 12 yd<sup>3</sup>) occurring above the surface of the water. STFATE does not incorporate the significant impact of wake turbulence on mixing the discharged material with the lake water. Dilution resulting from wake turbulence is likely the most important water and sediment quality consideration in the analysis of DCR discharges in the Great Lakes; therefore, the Simple Dilution Model will be used to predict water column impacts resulting from DCR discharges.

### Model Selection Conclusions

Near-field mixing is the most important consideration when analyzing the water quality aspect of DCR discharges in the Great Lakes. The Simple Dilution Model was created to simulate wastewater discharged from a moving cruise ship. This was the only model evaluated that is able to predict dilution caused by near-field mixing behind moving ships and is therefore the most accurate model available for the water quality analysis of DCR discharges.

STFATE was the only model that was evaluated that is able to model lake bottom impacts such as sediment distribution and accumulation. However, STFATE does not incorporate mixing effects caused by ship wake turbulence. Consequently, a spreadsheet model will be used to incorporate the applicable modeling concepts as well as other considerations such as discharge volumes, areas, natural deposition rates, particle settling velocities and mixing with existing sediments. This spreadsheet will be used to perform analysis of DCR sweeping effects. The Simple Dilution Model (Loehr et al. 2003) will be used in conjunction with an intuitive spreadsheet analysis to estimate the water and sediment impacts of DCR discharges.

### Detailed Water Quality Model Description

A Simple Dilution Model was published in OCEANS 2003 Proceedings (Loehr et al. 2003). This model was developed by an independent Science Advisory Panel to assist the Alaska Department of Environmental Conservation in evaluating the effects of wastewater

discharges from cruise ships in Alaskan waters. The cruise ships discharge wastewater above the water surface while moving; much like the DCR discharges from cargo vessels in the Great Lakes.

The panel reviewed several pertinent previous studies and concluded the following:

- The water displaced by a moving ship creates turbulent mixing upon its return astern of the ship.
- Large propellers on ships enhance mixing.
- Dilution is rapid and significant and depends on the size and speed of the vessel and the discharge rate.
- The cross-sectional mixing area behind a vessel rapidly expands to four times the cross-sectional area (beam × draft) of the submerged part of the vessel.

**Simple Dilution Model:** Dilution Factor =  $4 \times (\text{width} \times \text{draft} \times \text{speed}) / (\text{discharge rate})$

The cruise ships analyzed in the referenced paper had a beam of about 100 feet (30.5 meters), a draft of 25 feet (7.6 meters), and speeds ranging from 9 to 19 knots. The cruise ships are very similar in physical dimensions and speed to the large cargo vessels traveling on the Great Lakes. Great Lakes cargo vessels generally have 70 to 100 foot (21 to 30.5 meters) beams, 30 feet (9 meters) of draft or less, and can travel at speeds up to 17 knots (Great Lakes 2007 et al.1996). Wastewater discharge rates for cruise ships range from 250 to 500 gallons per minute (0.95 to 1.9 cubic meters per minute), which is similar to the 300 gallons per minute (1.1 cubic meters per minute) flow from a typical washdown hose on board a cargo vessel (CH2M Hill February 2007; USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization—Chemical Analyses Technical Memorandum).

In August 2001, the USEPA conducted a dye study of the discharges of four cruise ships. The Simple Dilution Model proved to be a conservative model. It underpredicted the dilution factors that were actually observed by the USEPA. The actual observed dilution factors were greater than that predicted by the model but were not more than 40 percent greater than that predicted by the model. Research on wastewater discharges from cruise ships has shown that a dilution factor of at least 12,000 can be expected within 15 minutes behind a large cruise ship (that is, a discharge of 12,000 mg/L copper would be diluted to 1 mg/L within 15 minutes) (Alaska DEC 2001).

#### Detailed Sediment Quality Model Description

The sediment quality model, developed by CH2M HILL specifically for this analysis, is a spreadsheet model that assumes discharged DCR sweepings are diluted via natural deposition or mixing with existing sediments. This model determines the required area over which sweepings must be uniformly distributed in order to dilute the sweepings sufficiently to meet sediment criteria. This modeling approach thus provides a comparison of the depositional area needed relative to the likely depositional area that actually occurs for DCR sweepings.

#### DCR discharge Data

Table 3 summarizes the data collected from log books of 31 Great Lakes cargo vessels for the 10-month period April 2004 and through January 2005. The data were collected for the USCG report (USCG, 2005). The database includes 2,777 entries for weight of discharged

DCR sweepings (Table 3). It also includes coordinates for starting and ending positions for 1,629 discharges. The coordinates were used to determine length of discharge and the discharge density (ratio of discharged mass/length of discharge) in order to determine the most dense discharges which would have the greatest impact.

TABLE 3  
Summary of DCR sweepings Database (April 2004–January 2005)

	DCR Sweepings Weight (lb)	Discharge Length (mi)	Discharge Density (lb/m) <sup>a</sup>
Average <sup>b</sup>	235	54	16
Median	175	43	4
Maximum <sup>c</sup>	600,000	n/a	n/a
10th percentile	50	16	1.1
95th percentile	678	114	18
99th percentile	1,500	308	92
Total discharged <sup>b</sup>	646,754	n/a	n/a

<sup>a</sup>Database includes 2,777 entries for mass of DCR sweepings, of which 1,629 have discharge length data.

<sup>b</sup>Total and average do not include discharges greater than 5,000 pounds (5 discharges).

<sup>c</sup>because of inaccurate reporting of latitude and longitude for some data points, it is difficult to determine the maximum discharge length and density. The 99th percentile is a more useful parameter.

Discharges ranged from zero to 600,000 pounds, but less than 1 percent of DCR discharges were greater than 1,500 pounds and only five discharges exceeded 5,000 pounds. The two largest discharges, 600,000 pounds and 400,000 lbs, were both discharges of iron, occurring in 2004. These two discharges occurred during transportation from Two Harbors, Minnesota to Gary, Indiana. The discharges greater than 5,000 pounds do not appear to be representative of DCR discharges and were likely due to extenuating circumstances. The database does not provide an explanation for discharges greater than 5,000 pounds. However, there have been documented occurrences when vessels have directly unloaded cargo from the cargo holds into the Great Lakes during emergency conditions. Two conditions that required such action included a vessel fire (to unload flammable cargo, such as coal) or when a vessel ran aground (unload cargo to reduce vessel draft). Directly unloading cargo from the vessel cargo holds is uncommon and is done in emergency situations when either loss of life or major damage to the ship would result (Anderson, T. 2007). The U.S. Coast Guard report (U.S. Coast Guard, 2002) observed a discharge of 66,150 pounds that was not due to discharge of sweepings. It was caused by a vessel casualty and emergency offloading operation and was not an operational discharge.

The average and median discharge masses obtained from this database are quite small, especially when considering the distance of the discharge. For example, the median discharge mass is 175 pounds, or 2.8 ft<sup>3</sup> of coal. Coal is the lightest of the DCR materials and consequently has the highest volume per unit weight. If the median discharge of 2.8 ft<sup>3</sup> was spread out over the median discharge distance of 43 miles, one would expect to see only a trace of the discharged material on the bottom of the lake.

The discharge density was calculated to identify discharges with the greatest density of dumping (i.e. the largest discharge mass over the smallest area). The median discharge density was 4 pounds/mile. Less than 1 percent of discharges had densities greater than 92 pounds/mile.

The USCG report (USCG, 2002) found that taconite constitutes 37 percent of the mass of DCR discharges (Table 4), while coal and limestone accounted for 27 percent and 28 percent, respectively, of the total discharged DCR mass.

TABLE 4  
DCR Sweepings Distribution

Material	% of Total Discharged Mass
Coal	27
Stone	28
Iron	37

*Note:* Data obtained from USCG report (USCG, 2002)

## Chemical Analysis Review

### Water Quality

Samples of both liquids and solids were collected from the decks and sumps of eight bulk dry cargo vessels. The analytical results of these samples were compared to chronic and acute water quality criteria that were determined by the Great Lakes Initiative (U.S. EPA 2005) and the USEPA (U.S. EPA 2007) for the protection of aquatic life and human health concerns.

Table 5 shows the chemical analysis data in terms of exceedance ratios for chronic water quality criteria as well as sediment criteria. Samples of DCR from the deck and the sump were tested individually, and within each of these samples, the solid and liquid portions were also tested separately. The exceedance ratio is calculated as follows:

$$\text{Exceedance Ratio} = \frac{\text{Analyte Concentration in Sample}}{\text{Chronic Water Quality Criteria or Sediment Criteria}}$$

The highest exceedance of chronic water quality criteria was observed in a sample of liquid collected from the sump of a vessel carrying western coal. The sample exceeded the chronic water quality criterion for pyrene by a factor of 31.4 and the aluminum criterion by a factor of 11. The third highest water quality exceedance was a liquid sample collected from a limestone vessel sump that exceeded the aluminum criterion by a factor of 10.9. These three are the only instances in which water quality criteria were exceeded by more than a factor of 10. Table 6 lists all values that exceeded the chronic water quality criteria and includes the sample analysis value (result), the chronic water criteria, and the exceedance ratio (analyte result: water criteria ratio). The results are listed by cargo type. Appendix A contains a key to the sample IDs in Table 6.

TABLE 5  
Exceedance Ratios

Analyte	Chronic Water Quality Criteria	Acute Water Quality Criteria	Units	Sediment Criteria	Units	Taconite				Eastern Coal				Western Coal				Limestone			
						Deck DCR sweepings		Sump		Deck DCR sweepings		Sump		Deck DCR sweepings		Sump		Deck DCR sweepings		Sump	
						Solids	Liquid	Solids	Liquid	Solids	Liquid	Solids	Liquid	Solids	Liquid	Solids	Liquid	Solids	Liquid	Solids	Liquid
Aluminum	0.087	0.750	mg/L													11					10.9
Anthracene	0.73	13	µg/L	57.2	µg/kg									1.5							
Arsenic	0.15	0.34	mg/L	9.79	mg/kg					1.3						3.0					
Benzo(a)anthracene	0.027	0.49	µg/L	108	µg/kg					1.4				1.2			3.4				
Benzo(a)pyrene	0.014	0.24	µg/L														2.6				
Cadmium	0.00025	0.0045	mg/L	0.99	mg/kg				2.7							1.1					8
Cadmium, dissolved	0.00021	0.00384	mg/L						1.8												7.2
Chromium	0.011	0.016	mg/L	43.4	mg/kg											4.9					
Chrysene	0.014	0.24	µg/L	166	µg/kg					1.7	3.2						7.1				
Copper	0.009	0.014	mg/L	31.6	mg/kg				2.9							61.4 <sup>(1)</sup>					1.5
Copper, dissolved	0.009	0.013	mg/L						2.2												1.4
Fluoranthene	6.16	33.6	µg/L	480	µg/kg									1.1							
Fluorene	3.9	70	µg/L	180	µg/kg					2.3											
Iron	1.000		mg/L				1.3		6.2								9.8				1.6
Lead	0.003	0.082	mg/L	35.8	mg/kg				2.3							6.6					2.5
Lead, dissolved	0.003	0.065	mg/L						1.2												1.2
Naphthalene	12	190	µg/L	176	µg/kg					17.6				2.0							
Nickel	0.052	0.47	mg/L	22.7	mg/kg					1.0						5.2					
Phenanthrene	6.3	30	µg/L	204	µg/kg					4.6				1.4							
Pyrene	0.014	0.24	µg/L	195	µg/kg					1.6	3.2			3.7	3.2		31.4				
Selenium	0.005	0.024	mg/L																		1.9
Selenium, dissolved	0.005	0.022	mg/L																		2.4
Zinc	0.120	0.120	mg/L	121	mg/kg				1.2	2.4						1.7					1.6

Note: **Bold** numbers also exceed acute water quality criteria.

<sup>(1)</sup> The value of copper is not representative of the typical copper values and is most likely due to contamination from foreign objects.

The set of more detailed sampling data for the chemical parameters that shows the highest exceedances of water quality is shown in Appendix B. Appendix B shows that only one sample had an extremely high value for pyrene. All of the liquid and solid samples that were collected exceeded pyrene water quality criteria by less than a factor of 6, except the lone sump liquid sample which exceeded criteria by a factor of 31.4. The exceedance of 31.4 does not appear to be representative of a typical sump discharge from a coal vessel. Further sampling is required to determine a consistent average pyrene concentration in the sump liquid. If the exceedance ratio of 31.4 is discarded as an outlier, then all liquids that were sampled would be within a factor of 11 of the chronic water quality criteria.

To compare the dry deck DCR sweepings with the sump slurry, the dry deck DCR sweepings were mixed with lake water. This mixture of dry deck DCR sweepings and lake water simulated the slurry that is washed overboard during sweeping events. Tables 5 and 6 show that the sump slurries had greater chemical parameter concentrations and a greater number of water quality criteria exceedances than did the deck DCR sweepings slurries. The deck DCR sweepings that are washed overboard have less contact time with water and are more distributed and dilute than the sump slurry discharge.

#### Mixing Zone Regulations Review

The water quality data obtained from sampling liquid from cargo vessel sumps and from mixing DCR sweepings with lake water showed that, for the most part, the discharged liquid meets water quality criteria. Water quality criteria are met when the exceedance ratio is less than 1.0. However, Table 6 shows that there are 30 instances when chronic water quality criteria were exceeded and eight instances for which acute water quality criteria were exceeded. There are only three instances in which chronic water quality criteria were exceeded by more than a factor of 10. The highest exceedance of acute water quality criteria was by a factor of 1.9 (see Chemical Analysis Review). The dilution factor is a parameter that determines, for a specific sample, how much dilution would be necessary to reach the acceptable water quality criteria. USEPA guidelines allow dilution factors of 10 as a default value for most discharges to surface water (U.S. EPA 1991). The Great Lake Initiative allows dilution factors of 10 or greater (U.S. EPA 2005).

The Technical Support Document for Water Quality-Based Toxics Control (TSD) (U.S. EPA 1991) published by the USEPA provides states and regions with guidance for analyzing adverse water quality impacts caused by toxic discharges to the surface waters of the United States.

**TABLE 6**  
Samples That Exceeded Chronic Water Quality Standards

Cargo	Vessel Name	Sample ID	Analyte	Result	Units	Water Chronic Criteria	Water Acute Criteria	Matrix	Exceedance Ratio (with chronic criteria)
Limestone	Earl W. Oglebay	CLELV2-LS-1	Cadmium	0.0022	mg/L	0.000246	0.0045	Water	8.9
Limestone	Earl W. Oglebay	CLELV2-LS-1	Cadmium, dissolved	0.0015	mg/L	0.000209	0.00384	Water	7.2
Limestone	Earl W. Oglebay	CLELV2-LS-1	Copper	0.0139	mg/L	0.0093	0.014	Water	1.5
Limestone	Earl W. Oglebay	CLELV2-LS-1	Iron	1.49	mg/L	1		Water	1.5
Limestone	Earl W. Oglebay	CLELV2-LS-1	Lead	0.0079	mg/L	0.0032	0.082	Water	2.5
Limestone	Earl W. Oglebay	CLELV2-LS-1	Lead, dissolved	0.0030	mg/L	0.0025	0.065	Water	1.2
Limestone	Earl W. Oglebay	CLELV2-LS-1	Selenium	0.0093	mg/L	0.005	0.024	Water	1.9
Limestone	Earl W. Oglebay	CLELV2-LS-1	Selenium, dissolved	0.0109	mg/L	0.0046	0.022	Water	2.4
Limestone	Earl W. Oglebay	CLELV2-LS-1	Zinc	0.191	mg/L	0.12	0.12	Water	1.6
Limestone	PathFinder	CLELV1-LS-1	Aluminum	0.951	mg/L	0.087	0.75	Water	10.9
Limestone	PathFinder	CLELV1-LS-1	Iron	1.60	mg/L	1		Water	1.6
Limestone	PathFinder	CLELV1-LS-1-D	Copper, dissolved	0.0130	mg/L	0.009	0.013	Water	1.4
Limestone	PathFinder	CLELV1-LS-1-D	Iron	1.52	mg/L	1		Water	1.5
Taconite	Edwin R. Gott	DLHTV1-LS-1	Cadmium	0.00059	mg/L	0.000246	0.0045	Water	2.4
Taconite	Edwin R. Gott	DLHTV1-LS-1	Cadmium, dissolved	0.00037	mg/L	0.000209	0.00384	Water	1.8
Taconite	Edwin R. Gott	DLHTV1-LS-1	Copper	0.0271	mg/L	0.0093	0.014	Water	2.9
Taconite	Edwin R. Gott	DLHTV1-LS-1	Copper, dissolved	0.0198	mg/L	0.009	0.013	Water	2.2
Taconite	Edwin R. Gott	DLHTV1-LS-1	Iron	6.22	mg/L	1		Water	6.2
Taconite	Edwin R. Gott	DLHTV1-LS-1	Lead	0.0075	mg/L	0.0032	0.082	Water	2.3
Taconite	Edwin R. Gott	DLHTV1-LS-1	Lead, dissolved	0.0029	mg/L	0.0025	0.065	Water	1.2
Taconite	Edwin R. Gott	DLHTV1-LS-1	Zinc	0.143	mg/L	0.12	0.12	Water	1.2
W. Coal	American Integrity	DLHCV2-LS-1	Aluminum	0.955	mg/L	0.087	0.75	Water	11

**TABLE 6**  
Samples That Exceeded Chronic Water Quality Standards

Cargo	Vessel Name	Sample ID	Analyte	Result	Units	Water Chronic Criteria	Water Acute Criteria	Matrix	Exceedance Ratio (with chronic criteria)
W. Coal	American Integrity	DLHCV2-LS-1	Benzo(a)anthracene	0.091	µg/L	0.027	0.49	Water	3.4
W. Coal	American Integrity	DLHCV2-LS-1	Benzo(a)pyrene	0.037	µg/L	0.014	0.24	Water	2.6
W. Coal	American Integrity	DLHCV2-LS-1	Chrysene	0.10	µg/L	0.014	0.24	Water	7.1
W. Coal	American Integrity	DLHCV2-LS-1	Iron	9.79	mg/L	1		Water	9.8
W. Coal	American Integrity	DLHCV2-LS-1	Pyrene	0.44	µg/L	0.014	0.24	Water	31.4
W. Coal	American Spirit	DLHCV1-LS-1	Pyrene	0.047	µg/L	0.014	0.24	Water	3.4
W. Coal	American Spirit	DLHCV1-LS-1-D	Pyrene	0.048	µg/L	0.014	0.24	Water	3.4
W. Coal	American Spirit	DLHCV1-LS-1RE	Pyrene	0.023	µg/L	0.014	0.24	Water	1.6

The USEPA TSD states that it is not always necessary to meet all water quality criteria within the discharge pipe to protect the integrity of the water body as a whole. Regulatory agencies generally allow small areas, known as mixing zones, near outfalls to exceed water quality criteria. The USEPA TSD also states that acute criteria may be exceeded if an analysis indicates that organisms drifting through the plume along the path of maximum exposure would not be exposed to concentrations exceeding the acute criteria when averaged over 1-hour (or appropriate site-specific) averaging period for acute criteria. Then, lethality to swimming or drifting organisms ordinarily should not be expected even for rather fast-acting toxicants. The USEPA TSD states that if a drifting organism travels through a plume for less than 15 minutes, a 1-hour average exposure would not be expected to exceed the acute criterion. Significant dilution due to wake turbulence is expected to occur in less than 15 minutes (Alaska DEC 2001) ensuring that DCR discharges will not exceed acute criteria and will not cause lethality to passing organisms.

Most states allow mixing zones but provide spatial dimensions to limit their size. Mixing zones for lakes are usually specified by surface area, width, cross-sectional area, and volume. The USEPA TSD provides four methods to determine appropriate regulations to ensure that discharged liquid that exceeds acute water quality criteria will not cause lethality to aquatic organisms.

1. Meet acute water quality criteria prior to discharge.
2. Discharge liquid at a velocity of 3 m/s or greater, and establish a regulatory mixing zone spatial limitation of 50 times the discharge length scale (square root of the cross-sectional area of the discharge pipe).
3. Meet the most restrictive of the following:
  - a. Meet the acute water quality criteria within 10 percent of the distance of the outfall to the edge of the specified regulatory mixing zone.
  - b. Meet the acute water quality criteria within a distance of 50 times the discharge length scale in any spatial direction. This restriction will ensure a dilution factor of at least 10 within this distance.
  - c. The acute water quality criteria within a distance of five times the local water depth in any horizontal direction from the outfall.
4. Provide data to the state regulatory agency showing that a drifting organism would not be exposed to 1-hour average concentrations exceeding the acute water quality criteria.

DCR sweeping is performed while the vessel is under way. Typical ship speeds are around 12 knots, or 6 m/s (Great Lakes 2007 et al.1996). DCR sweeping discharges fall and accelerate due to gravity before entering the water. Assuming the sweepings fall 16 feet (5 meters), the discharged liquid will have a downward velocity of 32 feet per second (9.8 meters per second) immediately before entering the water.

The relative infrequency of criteria exceedance, coupled with the intense dilution expected because of the momentum of the discharged liquid, will ensure that discharged liquid is diluted to a concentration below acute water quality criteria almost instantaneously, and no aquatic life will be exposed to lethal concentrations.

The Great Lakes Initiative (GLI) (U.S. EPA 2005) also provides guidance on mixing zones. It allows mixing zones if the discharger can demonstrate the following:

1. Show that the mixing zone does not interfere with or block passage of fish or aquatic life
2. Show that the mixing zone will be allowed only to the extent that the level of the pollutant permitted in the water body would not likely jeopardize the continued existence of any endangered or threatened species listed under section 4 of the ESA or result in the destruction or adverse modification of such species' critical habitat
3. Show that the mixing zone does not extend to drinking water intakes
4. Show that the mixing zone would not otherwise interfere with the designated or existing uses of the receiving water or downstream waters
5. Show that the mixing zone does not promote undesirable aquatic life or result in a dominance of nuisance species
6. Provide that by allowing additional mixing/dilution substances will not settle to form objectionable deposits; floating debris, oil, scum, and other matter in concentrations that form nuisances will not be produced; and objectionable color, odor, taste or turbidity will not be produced

Because of the relatively benign discharge characteristics (see Chemical Analysis Review), small quantities, and highly dispersed and rapidly mixed nature of the discharges, it is reasonable to believe that DCR discharges meet all the above criteria provided by the GLI, with one possible exception. Depending on the definition of "objectionable deposits," the DCR discharges may meet the criteria stated in item 6. However, the DCR discharges should not be considered "objectionable" because they are relatively benign materials and are dispersed in small amounts over vast areas of the lake. These deposits are released in such small quantities that natural sedimentation processes are able to dilute the deposits to concentrations below sediment criteria (see Sediment Quality Analysis).

## Sediment Quality

DCR sweepings samples were collected from the decks and sumps of vessels carrying coal, taconite, and limestone. The samples were evaluated for chemical concentrations in the DCR Sweepings Characterization Technical Memorandum (CH2M Hill February 2007; USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Chemical Analyses Technical Memorandum). This memo is included in Appendix C. The data obtained from the chemical analysis were compared directly to sediment guideline values. There are no separate parameters for chronic and acute contaminants. The measured values and sediment criteria for each analyte are listed in Table 7.

## Sample Analysis

Chemical analysis of the solid DCR sweepings obtained from the sumps and decks of various ships showed that only the coal DCR sweepings exceeded sediment criteria. The results of the chemical analysis for sediment samples are shown in Table 7. Chemical concentrations in the taconite and limestone DCR sweepings were below the sediment criteria for all analytes. As previously shown in Table 5, the highest exceedance of sediment criteria was in a sample of sump solids obtained from a vessel hauling western coal. This

504 sample exceeded the copper sediment criteria by a factor of 61.4. Table 7 provides more  
505 details for the samples that exceeded sediment criteria. A key to the sample IDs in Table 7 is  
506 provided in Appendix A.

TABLE 7  
Samples That Exceeded Sediment Criteria

Cargo	Vessel Name	Field ID	Analyte	Result	Units	Sediment Criteria	Matrix	Exceedance Ratio
E. Coal	American Courage	CLECV3-DS-1	Arsenic	11.3	mg/kg	9.79	SOIL	1.2
E. Coal	American Courage	CLECV3-DS-1	Chrysene	290	µg/kg	166	SOIL	1.7
E. Coal	American Courage	CLECV3-DS-1	Naphthalene	400	µg/kg	176	SOIL	2.3
E. Coal	American Courage	CLECV3-DS-1	Phenanthrene	580	µg/kg	204	SOIL	2.8
E. Coal	American Courage	CLECV3-DS-1-D	Arsenic	12.4	mg/kg	9.79	SOIL	1.3
E. Coal	American Courage	CLECV3-DS-1-D	Chrysene	240	µg/kg	166	SOIL	1.4
E. Coal	American Courage	CLECV3-DS-1-D	Naphthalene	430	µg/kg	176	SOIL	2.4
E. Coal	American Courage	CLECV3-DS-1-D	Nickel	23.2	mg/kg	22.7	SOIL	1.0
E. Coal	American Courage	CLECV3-DS-1-D	Phenanthrene	630	µg/kg	204	SOIL	3.1
E. Coal	American Courage	CLECV3-DS-1-D	Pyrene	200	µg/kg	195	SOIL	1.0
E. Coal	American Courage	CLECV3-DS-1-D	Zinc	295	mg/kg	121	SOIL	2.4
E. Coal	American Courage	CLECV3-DS-1DL	Chrysene	170	µg/kg	166	SOIL	1.0
E. Coal	American Courage	CLECV3-DS-1DL	Naphthalene	270	µg/kg	176	SOIL	1.5
E. Coal	American Courage	CLECV3-DS-1DL	Phenanthrene	420	µg/kg	204	SOIL	2.1
E. Coal	American Courage	CLECV3-DS-1DL	Pyrene	310	µg/kg	195	SOIL	1.6
E. Coal	American Republic	CLECV4-DS-1	Benzo(a)anthracene	150	µg/kg	108	SOIL	1.4
E. Coal	American Republic	CLECV4-DS-1	Chrysene	180	µg/kg	166	SOIL	1.1
E. Coal	American Republic	CLECV4-DS-1	Fluorene	180	µg/kg	77.4	SOIL	2.3
E. Coal	American Republic	CLECV4-DS-1	Naphthalene	3100	µg/kg	176	SOIL	17.6
E. Coal	American Republic	CLECV4-DS-1	Phenanthrene	930	µg/kg	204	SOIL	4.6
E. Coal	American Republic	CLECV4-DS-1	Pyrene	280	µg/kg	195	SOIL	1.4
W. Coal	American Integrity	DLHCV2-DS-1	Anthracene	88	µg/kg	57.2	SOIL	1.5
W. Coal	American Integrity	DLHCV2-DS-1	Benzo(a)anthracene	110	µg/kg	108	SOIL	1.0
W. Coal	American Integrity	DLHCV2-DS-1	Fluoranthene	480	µg/kg	423	SOIL	1.1
W. Coal	American Integrity	DLHCV2-DS-1	Naphthalene	360	µg/kg	176	SOIL	2.0

TABLE 7  
Samples That Exceeded Sediment Criteria

Cargo	Vessel Name	Field ID	Analyte	Result	Units	Sediment Criteria	Matrix	Exceedance Ratio
W. Coal	American Integrity	DLHCV2-DS-1	Phenanthrene	220	µg/kg	204	SOIL	1.1
W. Coal	American Integrity	DLHCV2-DS-1	Pyrene	720	µg/kg	195	SOIL	3.7
W. Coal	American Spirit	DLHCV1-DS-1	Anthracene	72	µg/kg	57.2	SOIL	1.3
W. Coal	American Spirit	DLHCV1-DS-1	Phenanthrene	210	µg/kg	204	SOIL	1.0
W. Coal	American Spirit	DLHCV1-DS-1	Pyrene	380	µg/kg	195	SOIL	1.9
W. Coal	American Spirit	DLHCV1-DS-1-D	Anthracene	79	µg/kg	57.2	SOIL	1.4
W. Coal	American Spirit	DLHCV1-DS-1-D	Benzo(a)anthracene	130	µg/kg	108	SOIL	1.2
W. Coal	American Spirit	DLHCV1-DS-1-D	Phenanthrene	280	µg/kg	204	SOIL	1.4
W. Coal	American Spirit	DLHCV1-DS-1-D	Pyrene	670	µg/kg	195	SOIL	3.4
W. Coal	American Spirit	DLHCV1-SS-1	Arsenic	19.0	mg/kg	9.79	SOIL	1.9
W. Coal	American Spirit	DLHCV1-SS-1	Chromium	206	mg/kg	43.4	SOIL	4.7
W. Coal	American Spirit	DLHCV1-SS-1	Copper	135	mg/kg	31.6	SOIL	4.3
W. Coal	American Spirit	DLHCV1-SS-1	Nickel	94.5	mg/kg	22.7	SOIL	4.2
W. Coal	American Spirit	DLHCV1-SS-1-D	Arsenic	23.5	mg/kg	9.79	SOIL	2.4
W. Coal	American Spirit	DLHCV1-SS-1-D	Cadmium	1.11	mg/kg	0.99	SOIL	1.1
W. Coal	American Spirit	DLHCV1-SS-1-D	Chromium	213	mg/kg	43.4	SOIL	4.9
W. Coal	American Spirit	DLHCV1-SS-1-D	Copper	1540	mg/kg	31.6	SOIL	48.7
W. Coal	American Spirit	DLHCV1-SS-1-D	Lead	237	mg/kg	35.8	SOIL	6.6
W. Coal	American Spirit	DLHCV1-SS-1-D	Nickel	111	mg/kg	22.7	SOIL	4.9
W. Coal	American Spirit	DLHCV1-SS-1-D	Zinc	201	mg/kg	121	SOIL	1.7
W. Coal	American Spirit	DLHCV1-SS-2	Arsenic	28.9	mg/kg	9.79	SOIL	3.0
W. Coal	American Spirit	DLHCV1-SS-2	Chromium	144	mg/kg	43.4	SOIL	3.3
W. Coal	American Spirit	DLHCV1-SS-2	Copper	1940	mg/kg	31.6	SOIL	61.4
W. Coal	American Spirit	DLHCV1-SS-2	Lead	91.6	mg/kg	35.8	SOIL	2.6
W. Coal	American Spirit	DLHCV1-SS-2	Nickel	119	mg/kg	22.7	SOIL	5.2

Most of the sediment exceedances were found in samples of coal deck DCR sweepings for polycyclic aromatic hydrocarbons (PAHs) such as naphthalene and chrysene. PAHs are organic compounds formed primarily by incomplete combustion of carbon-containing fuels such as coal. The deck DCR sweepings from all four coal vessels had sample results that exceeded the benchmark criteria for PAHs. The highest exceedance ratio was in a sample of deck DCR sweepings from an eastern coal vessel (CV4) that exceeded the naphthalene criteria by a factor of 17.6.

As seen in Table 7, there were only three instances in which a DCR sweepings solids sample exceeded the sediment criteria by more than a factor of 10. Two of the values were copper samples collected from two different sumps on the same western coal vessel (CV1). The third exceedance was the naphthalene exceedance on CV4. The two copper exceedances are not representative of typical DCR discharges. The samples of sump solids from CV1 appear to be high in overall metals because of the potential inclusion of foreign metallic objects. CV1 exceeded several metals criteria including cadmium, chromium, and copper while samples of sump and deck solids from the other three vessels did not exceed any metals criteria (Appendix D). All other sediment exceedances were found in samples of deck sweepings (Table 7). Additional chemical parameters that had the highest sediment exceedance ratios are documented in Appendix D.

In addition to the high copper values that were found in some sump samples, Table 7 indicates that the naphthalene exceedance ratio of 17.6 on CV4 is atypical. The naphthalene concentrations on other coal vessels all had exceedance ratios less than 2.6.

## Modeling Parameters

To provide a representative chemical parameter value for the sediment analysis, an average value was used to calculate the exceedance ratio and dilution factor. The dilution factor is a comparison of the concentrations (based on mass balance) to determine the amount of clean sediment that would need to be added to the sample so that the sediment and DCR mixture meets the sediment criteria. The dilution factor is based on mass balance and is defined as:

$$\text{Dilution Factor} = (C_d - C) / (C - C_s)$$

Where:

$C_d$  = Concentration of Parameter in Sweepings (mg/kg)

$C_s$  = Concentration of Parameter in Sediment (mg/kg)

$C$  = Desired Concentration (mg/kg)

The average recorded sample values were used to determine which parameter had the largest exceedance factor. This parameter, along with the calculated dilution factor was used in the sediment dilution modeling. Table 8 summarizes the average recorded sample values. The values were broken into two subsets, one for the deck sweeping samples and one for the sump solid samples. Some chemical parameters were not found in both types of samples and are therefore marked n/a.

TABLE 8  
Average Values of Sample Results and Average Exceedance Ratios

Analyte	Average Result		Solids Criteria	Units	Exceedance Ratio	
	Deck Sweeping	Sump Solids			Deck Sweeping	Sump Solids
Anthracene	87.9	n/a	57.2	µg/kg	1.54	n/a
Arsenic	11.6	22.6	9.79	mg/kg	1.19	2.31
Benzo(a)anthracene	126.3	n/a	108	µg/kg	1.17	n/a
Cadmium	n/a	1.1	0.99	mg/kg	n/a	1.12
Chromium	n/a	181.3	43.4	mg/kg	n/a	4.18
Chrysene	233.3	n/a	166	µg/kg	1.41	n/a
Copper	n/a	931.8	31.6	mg/kg	n/a	29.49
Dibenz(a,h)anthracene	38.0	n/a	33	µg/kg	1.15	n/a
Fluoranthene	480.0	n/a	423	µg/kg	1.13	n/a
Fluorene	133.0	n/a	77.4	µg/kg	1.72	n/a
Lead	n/a	177.2	35.8	mg/kg	n/a	4.95
Mercury	0.3	n/a	0.18	mg/kg	1.71	n/a
Naphthalene	637.8	n/a	176	µg/kg	3.62	n/a
Nickel	25.4	99.1	22.7	mg/kg	1.12	4.36
Phenanthrene	417.5	n/a	204	µg/kg	2.05	n/a
Pyrene	487.3	n/a	195	µg/kg	2.50	n/a
Zinc	295.0	299.0	121	mg/kg	2.44	2.47

As previously noted, the samples from one sump contained metal results unrepresentative of DCR, and consequently, the metal values from that sump were not included in the analysis. The next highest average exceedance ratio was for naphthalene, and so naphthalene was selected as the main chemical of concern. The average naphthalene concentration was 637.8 µg/kg, which exceeded the sediment criteria of 176 µg/kg by a factor 3.6. The average naphthalene value along with the sediment quality criteria was used to determine the dilution factor. The calculated dilution factor, 2.62, was then used in the above equation to determine the mass of sediment required to dilute coal DCR sweepings to meet sediment criteria.

## Modeling Results

### Water Quality Analysis

The greatest dilution required to meet water quality criteria for any DCR discharge was that of the sump containing coal. The coal sump slurry concentration of 0.44 µg/L of pyrene was 31.4 times greater than the chronic water quality criteria of 0.014 µg/L, but this concentration was atypical. Generally most chemical concentrations were within a factor of 10 of the chronic water quality criteria (see "Chemical Analysis Review").

The Simple Dilution Model was used to predict chemical parameter concentrations in the water column due to DCR discharges (Table 9). The mass of discharged deck DCR sweepings was taken as the average discharge obtained from the 2004 data (USCG, 2005) (see “Sweepings Discharge Data”). Discharge volumes of deck DCR sweepings were then calculated based on ratios of water to deck DCR sweepings that were published in the DCR Sweepings Slurry Simulation Technical Memorandum (CH2M Hill February 2007; USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Chemical Analyses Technical Memorandum). This memo is included in Appendix C.

The largest sump on the studied coal vessels was roughly 12 yd<sup>3</sup> (2,424 gallons) and the largest sump on the studied taconite vessels was 1.2 yd<sup>3</sup> (242 gallons). The sample from the limestone sumps did not show any water quality exceedances; therefore, dilution is not required to discharge this material. Volumes larger than the sump volume are also discharged when the tunnels are flooded during washdown events. Discharge rates are limited by sump pump capacity. The discharge rate of the sump slurry was assumed to be equal 400 gpm.

The Simple Dilution Model requires the following inputs:

- Vessel draft
- Vessel width
- Vessel speed
- Discharge flow rate

The draft was assumed 10 feet (3 meters) for an empty vessel. This is a very conservative assumption as the draft of a fully loaded ship is generally 30 feet (9.1 meters). The width of the vessel is assumed 68 feet (20.7 meters), which is the width of the smallest vessel that was sampled. Maximum vessel speeds are around 14 to 15 knots (Great Lakes 2007). A typical cruising speed was assumed to be 12 knots during discharge, although some cargo vessels can travel at 17 knots. The entire volume of discharged material was assumed to enter the water in 10 minutes. Shorter discharge duration results in a higher discharge rate and lower dilution factor. These are very conservative estimates because the data show that discharges on average occur over 54 miles over the course of 4 hours. The discharge flow rate is calculated based on the discharge volume and duration of discharge. The discharge flow rate is then entered into the Simple Dilution Model along with vessel speed, width, and draft. Even with these conservative assumptions, the dilution factors calculated with the Simple Dilution Model ranged from 27,000 to 1,020,000 for the various scenarios, which are much greater than that required to meet water quality standards.

TABLE 9  
Modeling Results (Water Quality)

DCR Sweepings Material	Coal (Deck)	Taconite (Deck)	Limestone (Deck)	Coal (Sump)	Taconite (Sump)	Limestone (Sump)
Parameter of concern	Pyrene	Iron	Cadmium	Pyrene	Iron	No exceedance
Initial parameter concentration (µg/L)	0.044	6.22	2.2	0.0045	1300	–
Chronic water quality criteria (µg/L)	0.00144	1	0.246	0.00144	1000	–
Acute water quality criteria (µg/L)	0.024	–	–	–	–	–
Dilution factor required to meet criteria	30.6	6.2	8.9	3.1	1.3	–

Mass of DCR discharge (lb)	150	233	270	—	—	—
Water to DCR sweepings ratio (gal./lb)	43	39	28	—	—	—
Volume of discharge (gallons)	6,450	9,087	7,560	4,000	4,000	—
Duration of discharge (s)	600	600	600	600	600	—
Vessel speed (knots)	12	12	12	12	12	—
Vessel width (ft)	68	68	68	68	68	—
Vessel draft (ft)	10.00	10.00	10.00	10.00	10.00	—
Distance of discharge (ft)	12,152	12,152	12,152	12,152	12,152	—
Rate of DCR discharge (gpm)	645	909	756	400	400	—
Estimated dilution factor	38,000	27,000	33,000	62,000	62,000	—
Est. parameter concentration behind vessel (µg/L)	1E-06	2E-04	7E-05	7E-08	2E-02	—

596

## 597 Frequency of Ship Discharges

598 The chronic water quality criteria generally are considered the maximum allowable  
599 concentration of a chemical parameter that will not have detrimental effects on organisms that  
600 are exposed indefinitely (U.S. EPA 1991). An analysis of shipping frequency by port was  
601 performed on 2004 DCR sweepings data (USCG, 2005) to determine the applicability of  
602 chronic water quality criteria to the DCR discharges. A summary of the number of ships  
603 arriving or departing from a port or an area of the Great Lakes in any four-day period from  
604 January 2004 through December 2006 is shown in Table 10. The maximum number of coal  
605 carrying ships was 8 from the ports of Duluth/Superior with the highest number of overall  
606 shipping being from taconite in the port of Cleveland (Table 10).

TABLE 10  
Shipping Frequency by Port

	Material	Maximum Shipping Frequency <sup>1</sup>
Duluth/Superior	Coal	8
Duluth/Superior	Taconite	6
Duluth/Superior	Limestone	N/A
Silver Bay	Coal	1
Silver Bay	Taconite	7
Silver Bay	Limestone	N/A
Southern Lake Michigan (includes several ports)	Coal	7
Southern Lake Michigan (includes several ports)	Taconite	7
Southern Lake Michigan (includes several ports)	Limestone	2
Cleveland	Coal	1
Cleveland	Taconite	9
Cleveland	Limestone	2
Ashtabula	Coal	2
Ashtabula	Taconite	4
Ashtabula	Limestone	N/A
Marble Head/Sandusky	Coal	4
Marble Head/Sandusky	Taconite	N/A
Marble Head/Sandusky	Limestone	3

*Note:* Maximum Number of Arrivals and Departures in a 4-day period

607

608 Table 10 shows that maximum number of coal DCR discharges in a given area did not exceed  
 609 eight discharges in 4 days during the 2004 shipping season. Because dilution occurs within 15  
 610 minutes and the highest frequency of ships from a port over a 4-day period is one every 12  
 611 hours, the chronic effects from these discharges are not significant.

## 612 Water Quality Analysis Conclusions

613 The Simple Dilution Model has shown that significant mixing and dilution can be expected  
 614 behind large moving vessels. Therefore, the chemical parameter concentrations in the DCR  
 615 discharges will be rapidly diluted below water quality criteria. The discharge of DCR  
 616 sweepings from a moving cargo vessel does not have any significant adverse impact on the  
 617 water column because the turbulence created by the displacement of water by the massive  
 618 cargo ships and the jetting caused by the large propellers mix the discharged DCR  
 619 sweepings with a large amount of water in a very short time. Significant dilution factors can  
 620 be expected due to this mixing within 15 minutes of discharge (Alaska DEC 2001).

## Sediment Quality Analysis

The high copper and naphthalene concentrations seen in the chemical analysis data are atypical of DCR discharges. There were no limestone or taconite solids samples, from the decks and sumps of bulk dry cargo vessels, which exceeded any sediment criteria. With the exception of the CV1 sumps, which appear to have been contaminated with foreign metallic substances, the only sediment criteria exceedances occurred in coal deck sweepings, which generally exceeded criteria for PAHs by a factor of less than 5. The highest average sediment exceedance was a naphthalene exceedance of 3.6 in coal deck sweepings. This exceedance ratio will be used to analyze potential sediment DCR concentrations from sweepings discharges (see "Chemical Analysis Review"). All the following sediment analyses include a safety factor of 10. The value of the safety factor was derived to protect against future increases in shipping cargo and any uncertainty with the data. A safety factor of 10 provides very conservative estimates for the calculated area required for DCR dilution. Mass data of DCR discharges were obtained from the USCG report (U.S. Coast Guard, 2002) for the 2000–2001 shipping season.

The following three sediment analyses were performed:

- Long-term sediment impact assuming dilution of coal DCR discharges due to natural sedimentation only
- Long term sediment impact assuming coal DCR discharges are diluted by mixing with the top 2 inches of existing sediment. Natural sedimentation rates are assumed to be negligible
- Short-term (1-year) impact due to the largest discharged mass over the smallest area

### Long-Term Sediment Analysis: Natural Sedimentation

CH2M HILL developed a spreadsheet analysis to determine the long-term impact on sediments due to the discharge of DCR sweepings in the Great Lakes. This analysis assumes that DCR discharges will be diluted only by natural sedimentation. Sedimentation rates are generally lower in the central basin because there is little suspended sediment from wind or river sources.

### Natural Sedimentation Rates

- **Lake Erie**—Reported sedimentation rates for Lake Erie range from 0.2 to 6.3 mm/yr (200 to 10,000 g/m<sup>2</sup>/yr). A value of 0.3 mm/yr was chosen as a conservative estimate of natural sedimentation in areas of DCR discharge.
- **Lake Michigan**—Reported sedimentation rates for Lake Michigan range from 60 to 2,500 g/m<sup>2</sup>/yr. A value of 0.3 mm/yr (500 g/m<sup>2</sup>/yr) was chosen as an estimate of natural sedimentation in areas of DCR discharge (Eadie et al.2000; Robbins et al.2001).
- **Lake Superior**—Reported sedimentation rates for Lake Superior range from 25 to 3,040 g/m<sup>2</sup>/yr. Values of 0.1 to 0.3 mm/yr were reported for the central basin of Lake Superior (Baker et al.1991; Evans et al.1981). This report stated a maximum sedimentation rate of 3.2 mm/yr. However, Klump et al. (1989) also report some areas of Lake Superior that receive virtually zero net long-term accumulation due to seasonal bottom currents that effectively scour the bottom. A value of 0.2 mm/yr (320 g/m<sup>2</sup>/yr)

was chosen as a conservative estimate of natural sedimentation in areas of DCR discharge.

A spreadsheet model was created to determine how much area would be needed when DCR is evenly distributed to dilute by natural sedimentation so as to meet the sediment criteria. The largest required area for dilution of coal occurs in Lake Superior, because the highest mass of coal is discharged in Lake Superior and because of the relatively low rate of natural sedimentation that occurs there in comparison to the other lakes. The modeling determined that in order to dilute the average observed naphthalene values, coal DCR sweepings would need to be spread for 10 miles over a 1,230-foot width (375-meter) (Table 11) to become diluted enough to meet sediment criteria by natural sedimentation. This assumes that DCR discharge (coal) for the entire lake would be distributed uniformly over the given area.

The area determined in the analysis included the conservative safety factor of 10. In reality, coal DCR sweepings are spread over an area much larger than 2.3 square miles (10 miles long by 1,230 feet wide) (see Appendix E); therefore the concentration of naphthalene in the sediments is much less than the sediment criterion of 176 mg/kg. Figures D-1, D-2, and D-3 show study areas that are about 1 mile wide (Mackey, S. D. 2006). The figures show tracklines for documented DCR discharges to the Great Lakes. It is clear that the DCR discharges are spread out over an area much larger than 2.3 square miles.

Also, some mixing of coal DCR sweepings with existing sediments can be expected, which would further reduce the concentration of naphthalene. The analysis is representative of a long-term (100-year) period in which the DCR sweepings evenly mix with naturally depositing sediment in a steady state condition. The analysis assumed discharge rates representative of 2000–2001 data (Potomac Management Group 2003) (Table 11), as well as a safety factor of 10. The factor of safety ensured a conservative value which accounts for uncertainty in future coal hauling trends and data uncertainty. It also assumes that the naturally depositing sediment has a chemical parameter concentration of zero.

Lake Erie has the largest impact because of coal DCR sweepings relative to its surface area. However, the required deposition area is only about 0.015 percent of the total surface area of Lake Erie, indicating that the discharge of coal DCR sweepings does not have a significant impact on the Lake.

TABLE 11  
Sediment Analysis: Natural Sedimentation

	Total Coal Discharged (lb/yr)	Mass of Sediment Required for Dilution (lb/yr)	Deposition Area Req'd. for Dilution with Safety Factor (m <sup>2</sup> )	% of Total Lake Area with Safety Factor	Width Req'd. for a 10-Mile-Long Discharge Zone (m)
Lake Erie	155,166	407,134	370,122	0.01438	230
Lake Michigan	80,133	210,258	191,144	0.00329	120
Lake Superior	160,373	420,797	597,723	0.00725	375

Note: Mass of discharged coal data (2000–2001) obtained from U.S. Coast Guard (2002).

## Long-Term Sediment Analysis: Mixing with Existing Sediments

DCR discharges can slowly mix over time with existing sediments. The mechanisms that can induce mixing include the movement of organisms that live in or near the top 2 inches of existing sediment and possible strong currents due to storms or density currents.

If a sample of the top 2 inches of sediment (conservatively, the most biologically active) (USEPA 2001) is collected, only a small fraction of this sample will contain DCR sweepings and the average concentration of DCR sweepings that aquatic organisms experience within this biologically active zone will meet sediment criteria. Even if there is no sediment and DCR mixing, the composite of the biologically active zone will not exceed sediment criteria. The DCR discharges should have little effect on organisms living in the top 2 inches of sediments. Klump et al. hypothesize that in some cases storms during isothermal conditions generate sufficient bottom currents at depth to scour the bottom very effectively.

A spreadsheet model was created to determine how much area would be needed to dilute the DCR chemical parameter by mixing with existing sediment to meet the sediment criterion. The analysis assumes the existing sediment is clean and has a chemical parameter concentration of zero. The largest required area for dilution of coal occurs in Lake Superior because it has the highest value of coal discharged. The modeling analysis simulated all the coal, discharged over 100 years in Lake Superior, evenly distributed over one location. From the modeling results, in order to dilute the highest average DCR chemical parameter (naphthalene), coal DCR sweepings would need to be spread for 10 miles over a 150-meter width (0.9 square miles) (Table 12) to become diluted enough to meet the sediment criterion.

In reality, coal DCR sweepings are spread over an area much larger than 0.9 square miles (see Appendix E); therefore, the concentration of naphthalene in the sediments is much less than the sediment criterion of 176 mg/kg. Figures E-1, E-2, and E-3 in Appendix E show study areas in yellow that are generally about 1 mile wide (Mackey, S. D. 2006). The figures show tracklines for documented DCR discharges to the Great Lakes.

The analysis assumed a 100-year period of sweeping at discharge rates representative of 2000–2001 data (Potomac Management Group 2003) (Table 12) as well as a factor of safety of 10 to account for uncertainty in future coal hauling trends, data uncertainty, and to be conservative.

Lake Erie has the largest impact from coal DCR sweepings relative to its surface area. However, the required deposition area is only about 0.009 percent of the total surface area of Lake Erie, indicating that the discharge of coal DCR sweepings does not have a significant impact on the lake.

TABLE 12  
Sediment Analysis: Mixing with Existing Sediment

	Total Coal Discharged Over 100 yr (lb)	Mass of Sediment Required for Dilution (lb)	Area of Sediment Required for Dilution (mi <sup>2</sup> )	% of Total Lake Area	Width Required for a 10-Mile-Long Discharge Zone (m)
Lake Erie	15,516,600	40,798,995	2,276,834	0.00884	145
Lake Michigan	8,013,300	21,069,989	1,175,835	0.00203	75
Lake Superior	16,037,300	42,168,111	2,353,240	0.00286	150

### Short-Term Sediment Analysis: Single Worst Discharge

A spreadsheet model was used to determine the area needed to dilute the single densest discharge of coal by natural sedimentation. The densest discharge of coal was taken as 92 lb/mile, which is the 99th percentile (that is, only 1 percent of discharges were denser) of all DCR discharges in the reviewed data (see DCR discharge Data). The largest required area for dilution of coal occurs in Lake Superior because of the relatively low rate of sedimentation. The modeling determined that to dilute the highest average chemical parameter concentration (naphthalene) by natural sedimentation over the course of 1 year, the discharge of 92 pounds would need to be spread for 1 mile over a 6.9-feet (2.1-meter) width (Table 13) to be diluted enough to meet sediment criteria through 1 year of natural sediment deposition. This assumes that the DCR discharge (coal) would be distributed uniformly over the given area and that no other DCR discharges will settle on the same location for 1 year. It also assumes that the naturally depositing sediment has a chemical parameter concentration of zero.

In reality, coal DCR sweepings are spread over an area much wider than 6.9 feet (2.1 meters) and in fact, a review of DCR locations indicate that they are spread out wider than 1 mile (1.6 kilometers). Figures D-1, D-2, and D-3 show study areas that are generally about 1 mile wide (Mackey, S. D. 2006). The figures show tracklines for documented DCR discharges to the Great Lakes.

This analysis assumes that the discharged coal DCR sweepings are uniformly distributed along the entire length of DCR sweepings because of a lack of more specific information on the discharge. It is unlikely that the DCR sweepings will be distributed uniformly along the entire length for a single sweeping event; rather, there will be lengths with no discharge at all, and other segments with large discharges. However, a safety factor of 10 was included in the analysis to account for this uncertainty and others.

It is reasonable to believe that the coal discharges would in fact spread out more than 6.9 feet (2.1 meters) in width, because the turbulent mixing zone created behind a moving cargo vessel is likely greater than the vessel's width (65.6 to 98 feet or 20 to 30 meters). In fact, studies suggest that mixing turbulence behind a moving vessel occurs in a vertical area 2.5 times the vessel width and 3 times the draft (Loehr et al. 2003). Coal is fairly light with a specific gravity of 1.4 and, therefore, may have a tendency to become entrained in the

TABLE 13  
Sediment Analysis: Most Dense Single Discharge (Natural Sedimentation)

Parameter of concern	Naphthalene
Parameter concentration (mg/kg)	638
Sediment quality criteria (mg/kg)	176
Lake Erie sedimentation rate (g/m <sup>2</sup> /yr)	500
Lake Michigan sedimentation rate (g/m <sup>2</sup> /yr)	500
Lake Superior sedimentation rate (g/m <sup>2</sup> /yr)	320
Mass of coal deck discharge (lb)	92
Safety factor	10
Length of discharge (miles)	1
Width required for 1-mile-long depositional zone—Lake Erie	1.4
Width required for 1-mile-long depositional zone—Lake Michigan (m)	1.4
Width required for 1-mile-long depositional zone—Lake Superior (m)	2.1

turbulent mixing zone behind the moving vessel and become distributed uniformly across a 98-foot (30-meter) width or larger. However, larger chunks of coal have higher settling velocities and may not become entrained. Overall, the DCR coal discharge would be expected to be at least 6.9 feet (2.1 meters) wide.

At a speed of 12 knots (20 ft/s), a coal particle discharged at the midpoint of the ship would be at its stern within 25 seconds assuming it is 1,000 feet (305 meters) long. If it is assumed that a particle that has fallen 15 feet (4.6 meters) or less within 25 seconds would become entrained and mixed in the turbulent mixing zone behind the vessel, the particles with settling velocities less than 0.6 ft/s (0.183 m/s) would become entrained. Grain size data are available for the solids samples that were collected for the Sweepings Characterization Memorandum (CH2M HILL 2007; USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Chemical Analyses Technical Memorandum). Table E-3 of Appendix F shows that all but the three largest grain sizes of coal settle at a velocity less than or equal to 0.2 m/s. More than 85 percent of the mass of Eastern Coal deck sweepings and more than 75 percent of the mass of Western Coal deck sweepings settles at less than 0.2 m/s. However, about 60 percent of the mass of the Western Coal sump solids has settling velocities greater than 0.2 m/s. Consequently, a significant percentage of the coal DCR material would be dispersed across an area equal to or greater than the width of the ship wake-generated mixing zone.

### Sediment Quality Analysis Conclusions

All the coal discharged to Lake Superior – the lake with the highest amount of coal discharge – in a given year when spread uniformly over a 10-mile by 375-meter area will meet sediment criteria when DCR and sediment dilution occurs because of natural sedimentation only. If natural sedimentation is considered negligible and dilution is assumed to occur through mixing with the top 2 inches of existing sediment, the same mass of coal must be spread over an area of 10 miles by 150 meters to meet sediment criteria.

The single densest discharge of coal was chosen to be the 99th percentile obtained from the 2004 database (USCG, 2005). Only 1 percent of discharges in this database were denser than 92 lb/mile. This most dense discharge must be spread over a width of 2.1 meters in order to be diluted by natural sedimentation to meet sediment criteria within 1 year. As previously stated, coal DCR sweepings are spread over an area much wider than 6.9 feet (2.1 meters) and in fact, a review of DCR locations indicate that they are spread out wider than 1 mile (1.6 kilometers).

Limestone and taconite solids do not exceed any sediment criteria. The required areas for dilution of discharged coal are much smaller than the areas that actually receive DCR discharges; therefore, the DCR discharges meet sediment criteria either by natural sedimentation or mixing with the top 2 inches of sediment.

### Mass Estimates of Sonar Images

In late 2006, DCR sweepings in the Great Lakes were analyzed using sidescan sonar data acquisition (Mackey, S. D. 2006). The sonar work identified a subset of potential DCR deposits on the lake bottom as potential sites for sediment sampling attempts. Sediment sampling confirmed the presence of DCR sweepings, such as taconite and coal, at several of these locations.

The sediment quality analysis above indicated that, in many instances, the average amount of DCR reaching the lake bottom would be negligible. A review of the DCR mass typically discharged indicates that a relatively small volume of DCR is discharged and would not be visible with a sonar investigation unless discharged in one location. Consequently, an analysis was conducted to determine a range of DCR mass needed to obtain the DCR sonar images that were observed.

Sonar images of select larger sites were used to estimate an approximate area that the DCR sweepings covered. The sonar study was conducted in areas of relatively high DCR activity. Although the sonar image reflects the area that the DCR sweepings cover, direct sampling of these areas determined that the DCR sweepings are not a continuous cover. DCR deck sweeping observations indicate material would be spread out over the entire sweeping area. Data from sediment samples indicate that the actual amount of DCR sweepings could make up as little as 5 percent of the area that the sonar images show as having a strong acoustic response. Two coal samples provided coverage results of 5 and 30 percent. An estimated sweepings thickness of 0.25 inch at both 5 and 100 percent coverage was used to determine an estimated volume range of DCR sweepings for a series of sonar images.

The ability of the side-scan sonar to detect acoustic anomalies depends upon the type of bottom background material, type of DCR, and coverage of DCR on the lake bottom. For example, coverage of one taconite pellet every square meter would not likely be visible, but coverage of taconite pellets of 10 percent or more of a reasonably sized area likely would be visible. The actual distribution of DCR on the lake bottom is unknown and, consequently, a range of coverages that would be expected to produce an acoustic anomaly was estimated.

The densities of coal, limestone, and taconite were used to calculate the potential weight of material that could have been deposited in the sweeping. The average density of anthracite coal (68.98 pounds per cubic foot or 1,105 kilogram per cubic meter) and bituminous coal (52.0 pounds per cubic foot or 833 kilograms per cubic meter) was used to determine the weight of coal. Some sites had multiple DCR sweepings that the sonar detected, and depending on the orientation and size of the DCR sweepings, they were considered either part of the same sweeping or different DCR sweepings. Consequently, the same site may have several sweeping areas listed. Table 14 lists the results of this analysis.

TABLE 14  
Volume and Weight of Coal Sample from Sampling Areas

Lake	Site	Sonar Sample ID	Total Sweeping Area (ft <sup>2</sup> )	5% Area (ft <sup>2</sup> )					100% Area (ft <sup>2</sup> )			
				5% Area (ft <sup>2</sup> )	Volume with 0.25" Thickness (ft <sup>3</sup> )	Weight of Coal (tons)	Weight of limestone (tons)	Weight of Taconite (tons)	Volume with 0.25" Thickness (ft <sup>3</sup> )	Weight of Coal (tons)	Weight of limestone (tons)	Weight of Taconite (tons)
Superior	Duluth	1	224890	11240	234	7.1	11.4	20.5	4685	142	227	410
		2	30560	1530	332	1.0	1.5	2.8	637	19	31	56
		3	22870	1140	24	0.7	1.2	2.1	476	14	23	42
		4	22870	1140	24	0.7	1.2	2.1	476	14	23	42
Superior	Silver Bay	1	53050	2650	55	1.7	2.7	4.8	1105	33	54	97
		2	35510	1775	37	1.1	1.8	3.2	740	22	36	65
		3	32170	1610	34	1.0	1.6	2.9	670	20	33	59
Michigan		1A	5270	265	5	0.2	0.3	0.5	110	3	5	10
		1B	8560	430	9	0.3	0.4	0.8	178	5	9	16
		2	31740	1590	33	1.0	1.6	2.9	661	20	32	58
		3	36150	1810	38	1.1	1.8	3.3	753	23	37	66
		4	7750	390	8	0.2	0.4	0.7	161	5	8	14
Erie	Marblehead	1	16140	810	17	0.5	0.8	1.5	336	10	16	29
		2	21890	1095	23	0.7	1.1	2.0	456	14	22	40
			154030	7700	160	4.9	7.8	14.0	3209	97	156	281
			27060	1350	28	0.9	1.4	2.5	564	17	27	49
			19370	970	20	0.6	1.0	1.8	404	12	20	35
		3	21060	1050	22	0.7	1.1	1.9	439	13	21	38
			7640	380	8	0.2	0.4	0.7	159	5	8	14
			18400	920	19	0.6	0.9	1.7	383	12	19	34
Erie	Cleveland	1A	8070	400	8	0.3	0.4	0.7	168	5	8	15
		1B	8610	430	9	0.3	0.4	0.8	179	5	9	16
		2	9680	480	10	0.3	0.5	0.9	202	6	10	18
		3	140420	7020	146	4.4	7.1	12.8	2925	89	142	256

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Some sonar images show deposits characterized as “subcircular rings” and “amorphous masses” that appear to be caused by large discrete discharges that would be unlikely caused by current DCR discharges based upon mass estimates, which are generally continuous and of small amounts of material. The largest mass of DCR discharge recorded in the 2004 database (USCG, 2005) was 3,500 pounds (1.75 tons). About 1 percent of the discharges were greater than or equal to 1,500 pounds (0.75 ton). DCR is typically discharged in very small amounts over vast areas of the lake. The median discharge was only 175 pounds (0.088 ton) (see DCR discharge Data) while the median discharge length was 43 miles. The 99th percentile discharge is only 92 lbs/mile. This would equate to about 1 1/2 five gallon buckets of coal DCR spread over a length of 1 mile. The coal would likely be spread out at least one ship width (>68') as the turbulent mixing zone is considered to be 2.5 times the width of the vessel (Loehr et al. 2003). It may be possible that the “linear” features observed on the sonar images represent the largest 1 percent of all DCR discharges. However, the typical DCR deck discharge likely would leave only a trace on a side-scan sonar image and may not be detectable at all due to the procedure used to discharge the material. Further research and field verification are required to determine the origin of deposits observed during the sidescan sonar study.

Many of the large discrete deposits observed during the sonar study (Mackey, S. D. 2006) are likely due to historical DCR discharges, but some may also be due to dredged material discharge, or other unknown sources. Verification sampling confirmed the presence of DCR at some of these sites, but most sites were not sampled. The mass of discharges was greater in the past, before the technology and the motivation to minimize discharges became commonplace. The Potomac Management Group report states that “substantial spillage may have occurred in the past during the loading process because of less sophisticated loading equipment than presently exists, perhaps because of a lower level of environmental concern” (Potomac Management Group 2003). It is possible that many of the images observed during side-scan sonar were created from DCR discharges in the past. Indeed, images from high frequency sonar have indicated that, in some instances, the surface of the lake bottom is smooth, whereas low frequency sonar has indicated the presence of many sweepings deposits just below the surface (Mackey, S. D. 2006). The side-scan sonar report hypothesized that historical sweepings deposits are likely the source of acoustic backscatter in areas where numerous complex patterns are observed in the low frequency sonar images.

The results (shown in Table 14) of the volume and weight calculations from the sampling areas range in values from 0.2 tons to 7.1 tons for coal for 5 percent coverage of the area, and from 3 tons to 142 tons for coal for 100 percent coverage. The average weights from the sonar analysis are 1.3 tons of coal, 2.0 tons of limestone, and 3.7 tons of taconite for 5 percent coverage, and 25.3 tons of coal, 40.6 tons of limestone, and 73.2 tons of taconite for 100 percent coverage. It is unlikely that many of the evaluated DCR sweepings are recent due to the estimated mass needed to produce the sonar images. The volume of sweepings has decreased over time because of refined loading and unloading methods. The estimated amount of DCR detected by sonar is much larger than what would be expected from a typical discharge. Most of the large deposits are likely historical discharges, but the largest 1 percent of current discharges may be responsible for some of the sonar images.

## Bioavailability

The chemical parameter concentration in the DCR material is not equivalent to the exposure that aquatic organisms would experience in the lake bottom sediment because not all the chemical parameter is generally bioavailable. Bioavailability refers to the amount of material that can be exposed to and ingested by aquatic organisms compared to the total amount of material. For example, when a chemical constituent is within a solid, it is not available to an aquatic organism. Chunks of DCR will not have all the chemical parameters immediately bioavailable since much of the chemical mass will be inside chunks and large pieces of the DCR.

The sediment concentration calculations used conservative analyses, such as assuming a factor of safety, demonstrating that actual DCR discharges occur over a much larger area than is needed to dilute DCR discharges through natural deposition or sediment mixing, and by assuming natural sediment deposition rates that are lower than the average depositional rates for the lakes. The concentrations of chemical parameters contained within the DCR in the lake bottom sediment are not entirely bioavailable, making the results of the sediment concentration analysis even more conservative.

If the chemical parameter in the combined DCR and sediment exceeds the sediment criterion, it does not mean that the amount of bioavailable chemical parameter exceeds the criterion. While the sediment quality analysis indicates sediment criteria should be met, testing organisms collected from sediment samples containing DCR deposits is an important step in assessing bioavailability to determine whether the chemical parameters at the concentrations present have an effect on aquatic organisms.

## Conclusions

The analysis of DCR and their effect on water quality and sediment quality took into account previously collected data, sonar images, and modeling. First, historical models were reviewed to determine if modeling software were available to perform the required analysis. The Simple Dilution Model was used for the water quality analysis, and a spreadsheet model was used to analyze potential sediment impacts. Next, information on the number of historical DCR discharges, maximum discharge mass, distance traveled during discharge, and the sweeping grain size distribution was reviewed. The historical information was organized by lake (Lake Superior, Lake Michigan, or Lake Erie) and by type of material discharged.

The water quality analysis concluded that the Simple Dilution Model has shown that significant mixing and dilution can be expected behind large moving vessels, and the concentrations of dissolved chemical parameters in the DCR discharges will be rapidly diluted to concentrations below water quality criteria. The discharge of DCR from a moving cargo vessel does not adversely affect the water column because turbulence created by the displacement of water by massive cargo ships and jetting caused by the large propellers mix discharged DCR with a large amount of water in a very short time.

Several DCR samples of deck and sump solids captured from different vessels were used to analyze for composition of coal, taconite, and limestone. The measured concentrations of the chemical parameters within the samples were compared to sediment criteria. The

comparison was considered the exceedance ratio, a way of determining which chemical parameters appear in the samples in the largest amounts relative to established criteria. A value greater than 1 indicated that a criterion had been exceeded. For chemical parameters with values greater than 1, the analysis also calculated a required dilution factor to determine the width of lake needed for DCR discharge to meet criteria through dilution by natural sedimentation. Limestone and taconite materials always met sediment criteria. Naphthalene in coal was found to have the highest average exceedance ratio, but coal DCR would meet sediment criteria through mixing with natural sedimentation when evenly distributed over an area 10 miles long by 1,230 feet (375 meters) for proper dilution.

The volume of historical DCR was analyzed to compare observed potential sonar DCR images. The analysis determined that some of the historical DCR observable through the sonar study are relatively large and most likely not attributable to recently documented typical DCR amounts. The loading and unloading of cargo has improved in recent times and the amount of DCR that is swept overboard has been reduced. DCR is typically discharged in very small amounts over vast areas of the lake. The 99th percentile discharge is only 92 lbs/mile (see DCR discharge Data). This would equate to about 1 1/2 five gallon buckets of coal DCR spread over a length of 1 mile. The coal would likely be spread out at least one ship width (>68') as the turbulent mixing zone is considered to be 2.5 times the width of the vessel (Loehr et al. 2003). However, further research and field verification are required to determine the origin of deposits observed during the sidescan sonar study.

Overall, the analyses determined that the current level of DCR discharges occurring in the Great Lakes should meet water and sediment quality criteria.

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## Appendix A Sample ID Key

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1031 APPENDIX A

## 1032 Vessel Abbreviations

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1033 Field ID Nomenclature:

1034 Departure Port, Vessel Type-Location where Sample was collected, Sample #

1035 CLE Port of Cleveland

1036 DLH Port of Duluth

1037 CV1 Coal Vessel 1 (American Spirit)

1038 CV2 Coal Vessel 2 (American Integrity)

1039 CV3 Coal Vessel 3 (American Courage)

1040 CV4 Coal Vessel 4 (American Republic)

1041 LV1 Limestone Vessel 1 (Pathfinder)

1042 LV2 Limestone Vessel 2 (Earl W. Oglebay)

1043 TV1 Taconite Vessel 1 (Edwin R. Gott)

1044 TV2 Taconite Vessel 2 (Paul R. Tregurtha)

1045 LS Liquid from Sump (liquid)

1046 SS Solids from Sump (solids)

1047 DS Deck sweepings (solids)

1048 Example: CLELV2-LS-1 is a sample collected from Limestone Vessel 2 (Earl W. Oglebay),  
1049 which departed from Cleveland. This was the first sample collected from the liquid material  
1050 in the sump.

TABLE A1  
Exceedances of Acute Water Quality Criteria

FieldID	Description
<b>Dry Deck DCR Discharges</b>	
DLHTV1-DS-1	Taconite deck discharge collected from Edwin R. Gott vessel
DLHTV2-DS-1	Taconite deck discharge collected from Paul R. Tegurtha vessel
DLHCV1-DS-1	Western coal deck discharge collected from American Spirit vessel
DLHCV2-DS-1	Western coal deck discharge collected from American Integrity vessel
CLECV3-DS-1	Eastern coal deck discharge collected from American Courage vessel
CLECV4-DS-1	Eastern coal deck discharge collected from American Republic vessel
CLELV1-DS-1	Limestone deck discharge collected from PathFinder vessel
CLELV2-DS-1	Limestone deck discharge collected from Earl W Oglebay vessel
<b>Sump Slurry</b>	
DLHTV1-LS-1	Taconite sump slurry collected from Edwin R. Gott vessel
DLHTV2-LS-1	Taconite sump slurry discharge collected from Paul R. Tegurtha vessel
DLHCV1-LS-1	Western coal sump slurry collected from American Spirit vessel
DLHCV2-LS-1	Western coal sump slurry collected from American Integrity vessel
CLELV1-LS-1	Limestone sump slurry collected from PathFinder vessel
CLELV2-LS-1	Limestone sump slurry collected from Earl W Oglebay vessel
WCOAL LKE	Western coal deck discharge simulated slurry with Lake Erie water
ECOAL LKE	Eastern coal deck discharge simulated slurry with Lake Erie water
LIME LKE	Limestone deck discharge simulated slurry with Lake Erie water
IRON LKE	Taconite deck discharge simulated slurry with Lake Erie water
WCOAL LKE	Western coal deck discharge simulated slurry with Lake Superior water
ECOAL LKE	Eastern coal deck discharge simulated slurry with Lake Superior water
LIME LKE-	Limestone deck discharge simulated slurry with Lake Superior water
IRON LKE	Taconite deck discharge simulated slurry with Lake Superior water

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**Appendix B**  
**Water Quality**

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## APPENDIX B

# Water Quality

TABLE B-1  
Exceedances of Acute Water Quality Criteria

Cargo	VesselName	FieldID	Analyte	Result	Units	Water Acute	Matrix	Analyte Result/ Water Criteria Ratio
Limestone	Earl W Oglebay	CLELV2-LS-1	Aluminum	0.297	mg/L	0.087	Water	3.4
Limestone	Earl W Oglebay	CLELV2-LS-1	Zinc	0.191	mg/L	0.12	Water	1.6
Limestone	PathFinder	CLELV1-LS-1	Aluminum	0.951	mg/L	0.087	Water	10.9
Limestone	PathFinder	CLELV1-LS-1-D	Aluminum	0.588	mg/L	0.087	Water	6.8
Taconite	Edwin R. Gott	DLHTV1-LS-1	Aluminum	0.287	mg/L	0.087	Water	3.3
Taconite	Edwin R. Gott	DLHTV1-LS-1	Copper	0.0271	mg/L	0.014	Water	1.9
Taconite	Edwin R. Gott	DLHTV1-LS-1	Copper, dissolved	0.0198	mg/L	0.013	Water	1.5
Taconite	Edwin R. Gott	DLHTV1-LS-1	Zinc	0.143	mg/L	0.12	Water	1.2
W. Coal	American Integrity	DLHCV2-LS-1	Aluminum	0.955	mg/L	0.087	Water	11.0
W. Coal	American Integrity	DLHCV2-LS-1	Pyrene	0.44	µg/L	0.24	Water	1.8

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TABLE B-2  
Complete Sample Data for Selected Water Chemical parameters

Sample ID	Analyte	Value	Units	Criteria	Analyte Result/Water Criteria Ratio
DLHCV1-LS-1	Aluminum	0.0802	mg/L	0.087	n/a
DLHTV2-LS-1	Aluminum	0.0802	mg/L	0.087	n/a
DLHTV1-LS-1	Aluminum	0.287	mg/L	0.087	3.3
CLELV2-LS-1	Aluminum	0.297	mg/L	0.087	3.4
CLELV1-LS-1	Aluminum	0.951	mg/L	0.087	10.9
DLHCV2-LS-1	Aluminum	0.955	mg/L	0.087	11.0
DLHCV1-DS-1	Aluminum	2640	mg/kg	—	—
DLHCV1-SS-1	Aluminum	204	mg/kg	—	—
DLHCV1-SS-2	Aluminum	1470	mg/kg	—	—
DLHCV2-DS-1	Aluminum	3470	mg/kg	—	—
DLHCV2-SS-1	Aluminum	3340	mg/kg	—	—
CLECV3-DS-1	Aluminum	2730	mg/kg	—	—
CLECV4-DS-1	Aluminum	1600	mg/kg	—	—

TABLE B-2  
Complete Sample Data for Selected Water Chemical parameters

Sample ID	Analyte	Value	Units	Criteria	Analyte Result/Water Criteria Ratio
CLELV1-DS-1	Aluminum	1250	mg/kg	—	—
CLELV1-SS-1	Aluminum	1090	mg/kg	—	—
CLELV2-DS-1	Aluminum	226	mg/kg	—	—
CLELV2-SS-1	Aluminum	97.4	mg/kg	—	—
CLELV2-SS-2	Aluminum	416	mg/kg	—	—
DLHTV1-DS-1	Aluminum	847	mg/kg	—	—
DLHTV1-SS-1	Aluminum	1270	mg/kg	—	—
DLHTV1-SS-2	Aluminum	1000	mg/kg	—	—
DLHTV2-DS-1	Aluminum	394	mg/kg	—	—
DLHTV2-SS-1	Aluminum	591	mg/kg	—	—
DLHTV2-SS-2	Aluminum	555	mg/kg	—	—
DLHCV1-LS-1	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
DLHCV2-LS-1	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
CLELV1-LS-1	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
CLELV2-LS-1	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
DLHTV1-LS-1	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
ECOALLKE	Aluminum	0.439	mg/L	0.087	5.0
IRON_LKE	Aluminum	0.0802	mg/L	0.087	n/a
LIME_LKE	Aluminum	0.0813	mg/L	0.087	0.9
WCOALLKE	Aluminum	0.267	mg/L	0.087	3.1
ECOALLKS	Aluminum	0.641	mg/L	0.087	7.4
IRON_LKS	Aluminum	0.0802	mg/L	0.087	n/a
LIME_LKS	Aluminum	0.0802	mg/L	0.087	n/a
WCOALLKS	Aluminum	0.542	mg/L	0.087	6.2
ECOALLKE	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
IRON_LKE	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
LIME_LKE	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
WCOALLKE	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
ECOALLKS	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
IRON_LKS	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
LIME_LKS	Aluminum, dissolved	0.0802	mg/L	0.087	n/a
WCOALLKS	Aluminum, dissolved	0.0802	mg/L	0.087	n/a

TABLE B-2  
Complete Sample Data for Selected Water Chemical parameters

Sample ID	Analyte	Value	Units	Criteria	Analyte Result/Water Criteria Ratio
DLHCV1-DS-1	Cadmium	0.427	mg/kg	0.99	0.4
DLHCV1-LS-1	Cadmium	0.000099	mg/L	0.000246	0.4
DLHCV1-SS-1	Cadmium	0.291	mg/kg	0.99	0.3
DLHCV1-SS-2	Cadmium	0.563	mg/kg	0.99	0.6
DLHCV2-DS-1	Cadmium	0.425	mg/kg	0.99	0.4
DLHCV2-LS-1	Cadmium	0.000099	mg/L	0.000246	0.4
DLHCV2-SS-1	Cadmium	0.0610	mg/kg	0.99	0.1
CLECV3-DS-1	Cadmium	0.456	mg/kg	0.99	0.5
CLECV4-DS-1	Cadmium	0.390	mg/kg	0.99	0.4
CLELV1-DS-1	Cadmium	0.288	mg/kg	0.99	0.3
CLELV1-LS-1	Cadmium	0.00015	mg/L	0.000246	0.6
CLELV1-SS-1	Cadmium	0.244	mg/kg	0.99	0.2
CLELV2-DS-1	Cadmium	0.223	mg/kg	0.99	0.2
CLELV2-LS-1	Cadmium	0.0022	mg/L	0.000246	8.9
CLELV2-SS-1	Cadmium	0.257	mg/kg	0.99	0.3
CLELV2-SS-2	Cadmium	0.0995	mg/kg	0.99	0.1
DLHTV1-DS-1	Cadmium	0.0380	mg/kg	0.99	0.0
DLHTV1-LS-1	Cadmium	0.00059	mg/L	0.000246	2.4
DLHTV1-SS-1	Cadmium	0.0547	mg/kg	0.99	0.1
DLHTV1-SS-2	Cadmium	0.0483	mg/kg	0.99	0.0
DLHTV2-DS-1	Cadmium	0.0730	mg/kg	0.99	0.1
DLHTV2-LS-1	Cadmium	0.000099	mg/L	0.000246	0.4
DLHTV2-SS-1	Cadmium	0.0534	mg/kg	0.99	0.1
DLHTV2-SS-2	Cadmium	0.0409	mg/kg	0.99	0.0
DLHCV1-LS-1	Cadmium, dissolved	0.000099	mg/L	0.0021	0.0
DLHCV2-LS-1	Cadmium, dissolved	0.000099	mg/L	0.0021	0.0
CLELV1-LS-1	Cadmium, dissolved	0.000099	mg/L	0.0021	0.0
CLELV2-LS-1	Cadmium, dissolved	0.0015	mg/L	0.0021	0.7
DLHTV1-LS-1	Cadmium, dissolved	0.00037	mg/L	0.0021	0.2
DLHTV2-LS-1	Cadmium, dissolved	0.000099	mg/L	0.0021	0.0
ECOALLKE	Cadmium	0.000099	mg/L	1	0.0
IRON_LKE	Cadmium	0.000099	mg/L	1	0.0

TABLE B-2  
Complete Sample Data for Selected Water Chemical parameters

Sample ID	Analyte	Value	Units	Criteria	Analyte Result/Water Criteria Ratio
LIME_LKE	Cadmium	0.000099	mg/L	1	0.0
WCOALLKE	Cadmium	0.000099	mg/L	1	0.0
ECOALLKS	Cadmium	0.000099	mg/L	1	0.0
IRON_LKS	Cadmium	0.000099	mg/L	1	0.0
LIME_LKS	Cadmium	0.000099	mg/L	1	0.0
WCOALLKS	Cadmium	0.000099	mg/L	1	0.0
ECOALLKE	Cadmium, dissolved	0.000099	mg/L	1	0.0
IRON_LKE	Cadmium, dissolved	0.000099	mg/L	1	0.0
LIME_LKE	Cadmium, dissolved	0.000099	mg/L	1	0.0
WCOALLKE	Cadmium, dissolved	0.000099	mg/L	1	0.0
ECOALLKS	Cadmium, dissolved	0.000099	mg/L	1	0.0
IRON_LKS	Cadmium, dissolved	0.000099	mg/L	1	0.0
LIME_LKS	Cadmium, dissolved	0.000099	mg/L	1	0.0
WCOALLKS	Cadmium, dissolved	0.000099	mg/L	1	0.0
DLHCV1-DS-1	Chrysene	67	µg/kg	166	0.4
DLHCV1-LS-1	Chrysene	0.02	µg/L	0.014	1.4
DLHCV1-LS-1RE	Chrysene	0.02	µg/L	0.014	1.4
DLHCV1-SS-1	Chrysene	0.72	µg/kg	166	0.0
DLHCV1-SS-1RE	Chrysene	1.8	µg/kg	166	0.0
DLHCV1-SS-2	Chrysene	6.9	µg/kg	166	0.0
DLHCV2-DS-1	Chrysene	75	µg/kg	166	0.5
DLHCV2-LS-1	Chrysene	0.10	µg/L	0.014	7.1
DLHCV2-SS-1	Chrysene	29	µg/kg	166	0.2
CLECV3-DS-1	Chrysene	290	µg/kg	166	1.7
CLECV3-DS-1DL	Chrysene	170	µg/kg	166	1.0
CLECV4-DS-1	Chrysene	180	µg/kg	166	1.1
WCOALLKE	Chrysene	0.02	µg/L	0.014	1.4
ECOALLKE	Chrysene	0.045	µg/L	0.014	3.2
ECOALLKS	Chrysene	0.050	µg/L	0.014	3.6
ECOALLKSRE	Chrysene	0.048	µg/L	0.014	3.4
WCOALLKS	Chrysene	0.02	µg/L	0.014	1.4

TABLE B-2  
Complete Sample Data for Selected Water Chemical parameters

Sample ID	Analyte	Value	Units	Criteria	Analyte Result/Water Criteria Ratio
DLHCV1-DS-1	Iron	3480	mg/kg	—	—
DLHCV1-LS-1	Iron	0.689	mg/L	1	0.7
DLHCV1-SS-1	Iron	286000	mg/kg	—	—
DLHCV1-SS-2	Iron	470000	mg/kg	—	—
DLHCV2-DS-1	Iron	5460	mg/kg	—	—
DLHCV2-LS-1	Iron	9.79	mg/L	1	9.8
DLHCV2-SS-1	Iron	2880	mg/kg	—	—
CLECV3-DS-1	Iron	16900	mg/kg	—	—
CLECV4-DS-1	Iron	5770	mg/kg	—	—
CLELV1-DS-1	Iron	2740	mg/kg	—	—
CLELV1-LS-1	Iron	1.60	mg/L	1	1.6
CLELV1-SS-1	Iron	1700	mg/kg	—	—
CLELV2-DS-1	Iron	861	mg/kg	—	—
CLELV2-LS-1	Iron	1.49	mg/L	1	1.5
CLELV2-SS-1	Iron	293000	mg/kg	—	—
CLELV2-SS-2	Iron	3130	mg/kg	—	—
DLHTV1-DS-1	Iron	515000	mg/kg	—	—
DLHTV1-LS-1	Iron	6.22	mg/L	1	6.2
DLHTV1-SS-1	Iron	536000	mg/kg	—	—
DLHTV1-SS-2	Iron	519000	mg/kg	—	—
DLHTV2-DS-1	Iron	310000	mg/kg	—	—
DLHTV2-LS-1	Iron	0.642	mg/L	1	0.6
DLHTV2-SS-1	Iron	366000	mg/kg	—	—
DLHTV2-SS-2	Iron	337000	mg/kg	—	—
DLHCV1-LS-1	Iron, dissolved	0.0522	mg/L	1	0.1
DLHCV2-LS-1	Iron, dissolved	0.0522	mg/L	1	0.1
CLELV1-LS-1	Iron, dissolved	0.0522	mg/L	1	0.1
CLELV2-LS-1	Iron, dissolved	0.101	mg/L	1	0.1
DLHTV1-LS-1	Iron, dissolved	0.810	mg/L	1	0.8
DLHTV2-LS-1	Iron, dissolved	0.0787	mg/L	1	0.1
ECOALLKE	Iron	0.757	mg/L	1	0.8
IRON_LKE	Iron	1.25	mg/L	1	1.3

TABLE B-2  
Complete Sample Data for Selected Water Chemical parameters

Sample ID	Analyte	Value	Units	Criteria	Analyte Result/Water Criteria Ratio
LIME_LKE	Iron	0.109	mg/L	1	0.1
WCOALLKE	Iron	0.204	mg/L	1	0.2
ECOALLKS	Iron	0.890	mg/L	1	0.9
IRON_LKS	Iron	0.150	mg/L	1	0.2
LIME_LKS	Iron	0.0522	mg/L	1	0.1
WCOALLKS	Iron	0.246	mg/L	1	0.2
ECOALLKE	Iron, dissolved	0.0522	mg/L	1	0.1
IRON_LKE	Iron, dissolved	0.0522	mg/L	1	0.1
LIME_LKE	Iron, dissolved	0.0522	mg/L	1	0.1
WCOALLKE	Iron, dissolved	0.0522	mg/L	1	0.1
ECOALLKS	Iron, dissolved	0.0522	mg/L	1	0.1
IRON_LKS	Iron, dissolved	0.0522	mg/L	1	0.1
LIME_LKS	Iron, dissolved	0.0522	mg/L	1	0.1
WCOALLKS	Iron, dissolved	0.0522	mg/L	1	0.1
DLHCV1-DS-1	Pyrene	380	µg/kg	195	1.9
DLHCV1-LS-1	Pyrene	0.047	µg/L	0.014	3.4
DLHCV1-LS-1RE	Pyrene	0.023	µg/L	0.014	1.6
DLHCV1-SS-1	Pyrene	8.2	µg/kg	195	0.0
DLHCV1-SS-1RE	Pyrene	3.6	µg/kg	195	0.0
DLHCV1-SS-2	Pyrene	15	µg/kg	195	0.1
DLHCV2-DS-1	Pyrene	720	µg/kg	195	3.7
DLHCV2-LS-1	Pyrene	0.44	µg/L	0.014	31.4
DLHCV2-SS-1	Pyrene	150	µg/kg	195	0.8
CLECV3-DS-1	Pyrene	190	µg/kg	195	1.0
CLECV3-DS-1DL	Pyrene	310	µg/kg	195	1.6
CLECV4-DS-1	Pyrene	280	µg/kg	195	1.4
WCOALLKE	Pyrene	0.079	µg/L	0.014	5.6
ECOALLKE	Pyrene	0.045	µg/L	0.014	3.2
ECOALLKS	Pyrene	0.040	µg/L	0.014	2.9
ECOALLKSRE	Pyrene	0.041	µg/L	0.014	2.9
WCOALLKS	Pyrene	0.054	µg/L	0.014	3.9

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Appendix C

**USCG Dry Cargo Sweepings Scientific  
Investigation: Sweepings Characterization –  
Chemical Analyses**

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## USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Chemical Analyses

PREPARED FOR: Parsons Brinckerhoff Quade & Douglas, Inc.

PREPARED BY: CH2M HILL

DATE: January 16, 2007

### Introduction

The purpose of this characterization task was to collect and analyze representative samples of dry cargo sweeping to aid in the evaluation the impacts of past, ongoing and potential future dry cargo sweeping practices in the Great Lakes.

As part of that effort, samples of dry cargo sweeping were collected for chemical, physical and biological analysis of from Great Lakes' cargo vessels. Four distinct types of sweepings were collected which included:

1. Taconite (iron ore)
2. Limestone
3. Coal from the western region (Wyoming Basin)
4. Coal from the eastern region (Appalachians)

### Project Quality Objectives

As stated previously, samples of dry cargo sweepings were collected from cargo vessels as critical inputs to the overall evaluation of the potential impacts to the receiving Great Lakes waters. Given this overall objective, this sampling and analysis effort was designed to:

- Collect representative samples of the four dry sweepings materials from cargo vessels
- Provide analytical data for identified key chemical, physical and biological parameters to assist in assessing the overall impacts of these sweepings on the Great Lakes
- Yield data of sufficient quality to support project decisions regarding the need for further study or impact control strategies

Therefore, the overall data quality objectives of this effort are to generate data of sufficient quality to allow for:

- Comparison of chemical concentration of cargo sweepings to established ecological and human health criteria
- Direct measurement of toxicological /biological impacts via established protocols
- Physical and chemical characteristics to allow modeling of sweeping releases into the Great Lakes.

Key to meeting this overall data quality objective is the selection of analytical and toxicological methods of appropriate sensitivity to allow criteria comparisons or to determine toxic effects. Of similar importance is the selection of sampling methods that ensure representative samples of cargo sweeping from the decks and sumps of each vessel.

## Sample Collection and Required Analyses

### Sampling Strategy and Techniques

During vessel loading and unloading operations, some of the cargo solids are inadvertently deposited on the decks and in the cargo hold walkways as spillage from the various loading/conveying systems. These materials can pose “slip, trip, and fall” hazards to ship’s personnel and a normally handled by water washing and moved directly overboard (deck sweepings) or collected into low lying wet sumps in the cargo hold areas where they are periodically pumped overboard. Based on previously conducted research, the mass of cargo sweeping generated per event vary from a few pounds to as much as 200 lbs (USCG, 2005).

Based on discussions with representatives of the Lake Carriers’ Association (LCA), results of a shipboard reconnaissance visit conducted by USCG, LCA, and CH2M HILL personnel in September, and a Data Quality Objectives planning meeting, a sampling strategy was developed to allow rapid collection of representative samples of the four dry cargo sweeping materials.

Because of the type of loading and unloading techniques employed, deck cargo sweepings are generated from the loss of material from dock-side conveying systems (loading) and from the shipboard conveying system during unloading. This sweeping must be cleared from the decks at the start of each voyage. Deck sweeping (washing) is accomplished by use of firefighting hoses delivering 200-400 gallons per minute of lake water to wash solid materials directly overboard. These activities may be conducted up to several times per week depending on the number of loading/unloading cycles.

Conversely, cargo hold sweepings are normally generated during unloading operations and are cleared from below-decks walkways by water wash down. These washings are collected into one or more (total number of sumps depends on the design of the individual vessel) low-lying sumps (typically 100-200 gallon each) equipped with dredge pumps. During wash down operations, these sumps may be cleared several times. Depending on the amount of cargo residue in these walkways, water wash-down and sump pump-out may only be conducted two or three times per month and cargo materials may stay in contact with wash water in these sumps for some period of days.

Analysis of these dry cargo sweeping techniques clearly identified the need to address the collection of deck sweepings separately from the collection of sump liquids and solids. Deck solids have relatively short contact time with wash water whereas sumps solids may have contact time on the order of several days. Therefore, sampling techniques were identified for collection of:

- Deck Sweeping Solids
- Cargo Sump Solids
- Cargo Sump Liquids

In addition to these field samples, quality control samples including field duplicates, field blanks, and matrix spikes/matrix spike duplicates were also collected. More details on the overall data approach to data quality are provided in the Measurement Quality Objectives (MQO) Section of this memorandum.

### Cargo Ship Visits

In order to collect the necessary samples, arrangements were made to visit eight cargo ships at ports on Lake Erie and Lake Superior. Table 1 identifies each vessel visited, its cargo, the location of the port facility, and dates that samples were collected. All samples were collected during the month of October, 2006. The sampling effort required two separate mobilizations.

**Mobilization 1:** Two CH2M HILL personnel from Corvallis, OR and Atlanta, GA and a representative of the Lake Carriers' Association (LCA) from Cleveland, OH traveled to Duluth, MN on September 30<sup>th</sup>. Samples of Western Coal and Taconite were collected over the next five days as ship schedules permitted. Typically, sampling on ship occurred in a three to five hour window during loading operations. Equipment preparation before the event, follow-up preparation of sample chains of custody (COCs), and packaging of samples for shipping required an additional four to five hours. Following the completion of taconite and western coal sampling, one CH2M HILL person and the LCA representative traveled to Cleveland on October 5<sup>th</sup> to stage for collection of eastern coal and limestone samples. Weather on the Great Lakes and changing ship schedules caused some delay in gaining access to the remaining vessels. Eastern Coal samples were collected from two vessels as indicated in Table 1 during the week of October 9<sup>th</sup> with assistance from a second CH2M HILL person traveling by vehicle from Dayton, OH. Weather and ship schedules forced the team to demobilize later that week as no firm schedule could be established for collection of samples from the final limestone cargo vessel.

**Mobilization 2:** During the week of October 23<sup>rd</sup>, the final limestone samples were collected from the second vessel (Table 1). CH2M HILL personnel mobilized from Corvallis, OR and Cleveland, OH and were joined by the LCA representative from Cleveland. Sampling was completed in the evening hours of October 27<sup>th</sup> and samples were shipped on Saturday for Monday delivery to the laboratories.

### Deck Sweepings

Deck sweeping solids were dust and coarse grain materials, which accumulate on the outer deck surfaces of each vessel. Prior to collection of deck solid samples, a rapid survey of the deck surface of the vessel was conducted to identify areas that contain significant layers of dust or deposits of dry materials. Typically, these areas were located on a track between the inshore side of the vessel (loading side) and the area around the cargo hold transited by the conveyer boom (Figure 1). Samples were collected using a new Teflon brush and polyethylene scoop. Each vessel had from 20 to 30 cargo holds, and solid materials were collected from as many hold areas as needed to provide the necessary sample volume. Typically, 10-12 hold areas of about 1 meter square each were swept for sample collection (Figure 2). Solid samples were first composited in clean, 2-L polyethylene pail and sub-samples were transferred to individual sample containers as required by each analytical method. Given the mechanism of deposition of solids onto the deck surfaces, solids were highly mixed and were expected to be representative of the cargo materials being loaded.

During the sampling, the mass of dry cargo on the deck was roughly estimated and found to be generally consistent with the mass of sweepings reported in ships logs as documented in previous reports (USCG, 2005).

Direct collection of deck sweepings during the wash down operation was not feasible because of logistic and safety considerations. An approach was developed to simulate deck sweepings wash samples by collecting additional volumes of solids and preparing the slurry in the laboratory using water from Lake Erie and Lake Superior. This methodology is described in the memorandum titled *Dry Cargo Sweepings Slurry Simulation* (CH2M HILL, October 2006, Attachment 1). In this fashion, six total samples were created for all cargo types using the following ratios with lake water from Erie and Superior:

- Taconite: 39 lbs of solids to 1 lb of water
- Coal: 28 lbs of solids to 1 lb of water
- Limestone: 43 lbs of solids to 1 lb of water

Deck solids from each of the two vessels per cargo type were added on a 50/50 mass basis to the water. These samples were then submitted to the laboratories for the required analyses.

#### Sump Solids and Liquids

Samples from the below decks sumps were collected following a rapid survey of the area to determine the number and condition of each sump. In some cases, two sumps were available; in other cases up to eight sumps were available, but only one or two sumps contained water and solid materials. Table 2 presents a summary of sump conditions by vessel.

For each sump, the protective steel grating was removed and the sump probed using a clean wooden dowel to determine liquid depth and presence of solids. Generally sumps were about 60 cm deep and varied in length and width. For sump solids, material was collected using a clean 1-L glass jar and materials were transferred to the required individual sample containers. For liquid samples, a single sample (or a single composite of two sumps where available) were collected as sequential volumes using clean 1-L glass jar and transferring to the required method sample containers. Liquid samples for the bioassay methods were collected in a four liter polyethylene Cubetainer ©. Filtered samples for metals were collected using a clean 40-mL plastic syringe equipped with a 0.54 micron in-line filter. Sample volumes were withdrawn sequentially for each sump and filtered into the acid-preserved 250-mL polyethylene sample bottles. Typical sump conditions are shown in Figures 3, 4 and 5 for taconite, coal and limestone cargos, respectively.

In every case, all samples were stored in 60-L plastic coolers and transferred off each vessel to a sample holding area where sample chain-of-custodies were completed, and samples were packed for Federal Express shipping to the various laboratories.

#### Analytical Methodology

Analytical methodologies were selected to generate data of sufficient quality to support the identified project data quality objectives. As an outcome of the Data Quality Objectives meeting held in Duluth, MN on September 27 specific analytical methods and target analytes were identified for the cargo sweepings characterizations *USCG Dry Cargo*

*Sweepings Scientific Investigation: Characterization Methods Review* (CH2M HILL, December 2006). Table 3 presents a summary of methods by sample matrix. Analytes associated with each method are shown in Attachment 2.

### Field and Quality Control Samples

Field samples of cargo sweepings and sump solids and liquids for each cargo and vessel are summarized in Table 4. As previously stated, samples from two vessels for each cargo type were collected to access the variability between cargo materials.

A number of quality control samples were also collected during the field effort. These samples are described in the next section and summarized in Table 5.

### Measurement Quality Objectives (MQO)

MQO's were established for all analyses by monitoring and controlling the normal data quality indicators (representativeness, bias, accuracy, precision, sensitivity, comparability, and completeness).

**Precision** is the degree of agreement among replicate measurements of the same property. For this study, field duplicate samples will be collected for all cargo types and matrices. In some cases, such as field filtration of samples for dissolved metals, a duplicate sub-sample will be processed through a separate filter. In the assessment of overall precision, the laboratory will often use reference samples (e.g., laboratory control samples or laboratory duplicate samples) to assess precision associated with sample preparation and analysis.)

**Bias** is the systematic measurement of processes that cause errors in one direction for a particular measurement. Bias is measured through analysis of standards of known concentrations, through proper instrument calibration, and in some cases, inter-laboratory comparisons. For this study, bias will be controlled in the laboratory by QC measures (instrument calibration standards, method blanks, etc.) associated with each method.

**Sensitivity** is defined as the minimum concentration above which the data user has reasonable confidence that the parameter was consistently detected and quantified. Analytical reporting limits are developed from method detection limits that are measured per 40 CFR Part 136. In the cases of toxic organics and metals, the reporting limits for each analyte should be approximately 3 to 5 times lower (where possible by the method) than the concentration of concern identified in the criteria list. For nutrients and physical parameters, the requirements are based on comparison to typical concentrations expected in the Great Lakes waters.

**Representativeness** is the degree to which a measurement accurately and precisely represents a condition or characteristic of a population at the sampling location. This measure is qualitative and the degree of representativeness depends on the sampling strategy and selection of locations.

**Completeness** – In general, a completeness goal of 100% is desired. A completeness of 100% would indicate that analyses were completed for all methods and analytes planned for each sampling location, and that all of the resulting data was useable. However, many factors (weather, sample location accessibility, matrix effects) generally force the actual completeness to a lower value. For this effort, the completeness goal is 90%.

**Comparability** is an expression of the level of confidence that two or more data sets can be used to support a common analysis of a condition or characteristic. For this effort, the data set being collected for dry cargo sweeping will form a baseline. In order to ensure comparability with future efforts, SOPs for sampling will be employed and updated to reflect actual practice and standard, and the analytical methodology employed will be well documented.

A relatively conservative approach was taken in developing the required number of field quality control samples as the number of parent field samples were rather small, which resulted in a larger number of field QC than would normally be expected using a standard EPA Superfund or RCRA approach. Field QC samples included:

- Field Duplicates – One sample collected for each cargo type and vessel combination.
- Field Blanks: One sample collected for each cargo type using reagent grade water for in-line filters used to collect field filtered water samples to assess any bias introduced by field collection methods.
- Matrix Spike/Matrix Spike Duplicate (or Duplicate in the case of metals): One sample pair collected for each cargo type and matrix combination for metals and semi-volatile organics only.

In addition to these field QC samples, a number of laboratory quality control samples were also analyzed. These included method blanks, laboratory control samples (LCS), and interference check samples. The type and frequencies of specific QC samples performed by the laboratory depend on the specified analytical method. Internal QC methods require performance on a sample batch basis and include analyses of method blanks, LCSs, and actual environmental samples such as duplicates, matrix spikes, and matrix spike duplicates. Additional QC is incorporated into the analytical sequence.

## **Analytical Laboratories**

Samples for chemical and physical analyses were shipped to Lancaster Laboratory of Lancaster, PA. Analyses of nutrients were performed by the CH2M HILL Applied Science Laboratory. Bioassay samples were submitted to EnviroSystems, Inc. of Hampton, New Hampshire.

## **Sample Results**

Analytical results for all samples collected as part of this effort are presented in Attachment 3. A complete copy of all laboratory data packages is provided on a CD in Attachment 4. Bioassay results are reported in a separate memorandum *USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Toxicological Analyses* (CH2M HILL, January 2007).

## **Data Quality Assessment**

### **Inter-vessel Comparison of Results for Individual Cargos**

Samples results from each of the two vessels carrying the same cargo were compared to assess the variability of the cargo material itself. In order to facilitate a rapid comparison, the results of Vessel 1 and Vessel 2 were compared by calculating the ratio of their

respective concentrations. A ratio of 1 indicates equivalent results for Vessel 1 and Vessel 2. These ratios are summarized in Table 6. In general, these ratios indicate reasonable comparability between vessels of the same cargo. However, sump liquid samples show considerably greater variability which may be indicative of differences in solid to liquid volumes, solid surface areas, and/or solid/liquid contact times.

### Field Duplicate Results

Field duplicate samples were collected for deck sweeping, sump solids and sump liquid samples as indicated previously in Table 5. Results for the native samples and corresponding field duplicates were compared calculating the ratio of concentration results. These ratios are summarized for all parameters detected in the native samples in Table 7. A ratio of 1.0 indicates that native and field duplicate results were equivalent. Generally ratios were in the range of 0.8 to 1.3 indicating very good analytical precision.

### Assessment of Laboratory Data Quality Indicators

A streamlined data quality evaluation was performed on the data to identify any significant issues that would adversely impact data usability. Surrogate recoveries, laboratory control sample results, MS/MSD results, and blank sample results were reviewed. For a small number of field samples, analyte concentrations exceeded calibration ranges and the samples were reanalyzed following dilution. Both native and diluted results are reported.

LCS and MS/MSD results were generally good with some variability seen for results where native concentrations significantly exceeded the spiking levels. Some low level contamination was seen in results for general chemistry parameters (nitrate, chloride, etc.), as well as calcium and aluminum in metals blanks.

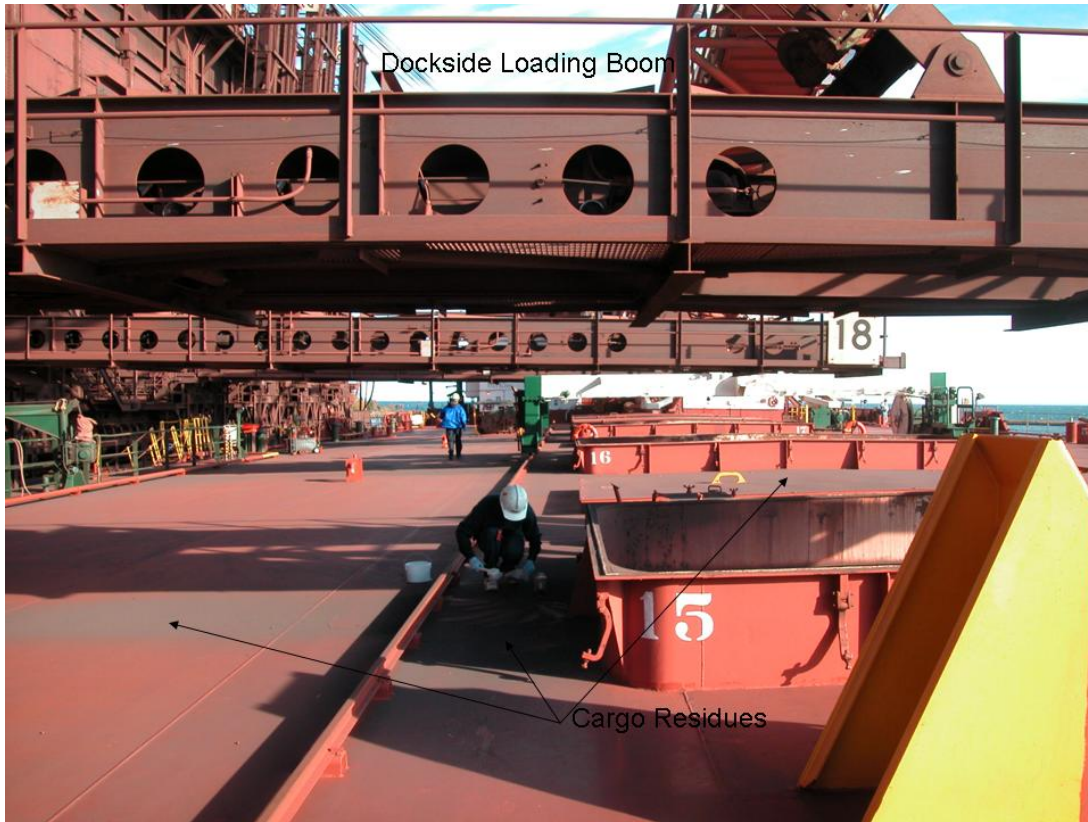
### Comparison of Sample Results to Criteria

The ultimate data quality objective was to facilitate a comparison of cargo sweeping results to benchmark criteria previously established. In order to be conservative and to acknowledge some variability in the results for similar cargo in different vessels, the maximum result for each combination of cargo type and matrix was compared to each benchmark criterion for chronic effects. The benchmark criteria used were conservative (i.e., if concentrations are under the criterion there would be little to no likelihood of toxic effects, and for exceedances less than 10 times the criterion there may be an indication of toxic effects. Also, the criteria are intended for comparison to environmental media (i.e., in surface water or sediment after the sweepings have mixed with native water or sediment) thus direct comparison to the source material (i.e., sweepings) is a large overestimate of toxic effects. To make these comparisons more clear, the maximum concentration result was divided by its corresponding criterion to develop a ratio. Ratios greater than one indicate an exceedance for that analyte. Table 8 presents the results of those comparisons. Twenty-one analytes exceeded criteria in one or more samples. The majority of those exceeding criteria had ratios lower than 10, indicating sample results were ten times or less above the criteria. Only copper and pyrene had higher exceedance ratios in Western Coal Sump solids and liquids, respectively.

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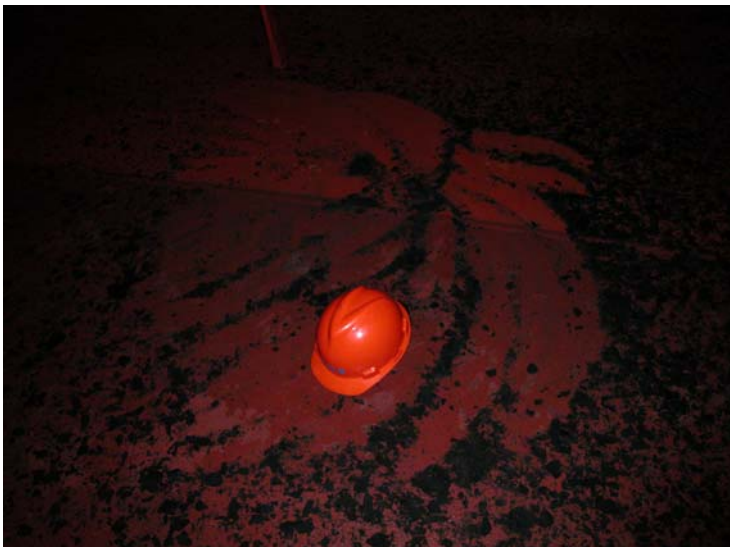
1343 Figure 1

1344 Typical Cargo Residue Deck Deposition Pattern – Taconite (M/V Edwin R. Gott)



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1346 Figure 2

1347 Typical Sample Collection Size – W. Coal (M/V American Integrity) and Taconite (M/V  
1348 Edwin R. Gott)

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1352 Figure 3

1353 Sump Conditions – M/V Edwin R. Gott (Taconite)



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1355 Figure 4

1356 Sump Conditions – M/V American Integrity (Western Coal)



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1359 Figure 5

1360 Sump conditions – M/V Pathfinder (Limestone)



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ATTACHMENT 1

TECHNICAL MEMORANDUM

CH2MHILL

## Dry Cargo Sweepings Slurry Simulation

PREPARED FOR: Project Team

PREPARED BY: Jamie Maughan

DATE: October 6, 2006

One of the objectives of the sweepings characterization was to simulate the “slurry” of dry cargo residue that was washed off the deck during a sweeping event. In order to simulate the slurry we estimated the following:

- Average mass of residue from a deck sweeping event
- Average volume of water from a deck sweeping event
- Concentration of sweepings in the slurry going over board

We estimated the average mass of sweeping by extracting from the USCG data base for 2004 all reported sweeping events from decks. We calculated the average mass from all events separately for iron, stone, and coal. We estimated the volume of water by applying the time of washing for the same events to the estimated rate of washing. The actual wash time was estimated as half the time reported as the washing operation to account for breaks, moving the hose, and hosing of areas with no sweepings. The washing rate was estimated as half the typical hose capacity (half of 300 gallons per minute, or 150 gallons per minute). Half the capacity was used to account for using less than full pressure and loss of water through leaks. This estimated volume of water was again divided in half as a conservative safety factor (i.e. over estimate the concentration of dry cargo residue in the slurry). The estimated mass of residue was divided by the estimated volume of water to derive an estimated slurry concentration. The results are summarized below.

	mean sweeping Wt.	st. dev.	count	Wash water (lbs)	lbs water to lbs sweeping	lbs water to lbs sweeping Safety factor (divided by 2)	gallons of water to lbs of sweepings
Iron	233.33	365.39	239	73451.04603	314.78832	157.3941578	39
Stone	269.39	240.54	74	59736.48649	221.74567	110.8728367	28
Coal	150.38	117.52	154	51391.55844	341.75231	170.8761551	43

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**Appendix D**  
**Sediment Quality**

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## APPENDIX D

# Sediment Quality

TABLE C1  
Complete Sample Data for Selected Sediment Chemical parameters

Sample ID	Analyte	Result	Units	Criteria	Analyte Result / Water Criteria Ratio
CLECV3-DS-1	Copper	13.9	mg/kg	31.6	0.4
CLECV3-DS-1-D	Copper	15.6	mg/kg	31.6	0.5
CLECV3-DS-1MS	Copper	21.5	mg/kg	31.6	na
CLECV3-DS-1SD	Copper	19.0	mg/kg	31.6	na
CLECV4-DS-1	Copper	24.2	mg/kg	31.6	0.8
DLHCV1-DS-1	Copper	11.4	mg/kg	31.6	0.4
DLHCV1-DS-1-D	Copper	12.2	mg/kg	31.6	0.4
DLHCV1-DS-1MS	Copper	16.6	mg/kg	31.6	na
DLHCV1-DS-1SD	Copper	13.7	mg/kg	31.6	na
DLHCV1-LS-1	Copper	0.0052	mg/L	0.0093	0.6
DLHCV1-LS-1-D	Copper	0.0041	mg/L	0.0093	0.4
DLHCV1-LS-1LR	Copper	4.9	µg/L	0.0093	0.5
DLHCV1-LS-1MS	Copper	62.3	µg/L	0.0093	na
DLHCV1-LS-1SD	Copper	60.6	µg/L	0.0093	na
DLHCV1-SS-1	Copper	135	mg/kg	31.6	4.3
DLHCV1-SS-1-D	Copper	1540	mg/kg	31.6	48.7
DLHCV1-SS-1MS	Copper	112	mg/kg	31.6	na
DLHCV1-SS-2	Copper	1940	mg/kg	31.6	61.4
DLHCV2-DS-1	Copper	19.0	mg/kg	31.6	0.6
DLHCV2-LS-1	Copper	0.0056	mg/L	0.0093	0.6
DLHCV2-SS-1	Copper	14.8	mg/kg	31.6	0.5
ECOALLKE	Copper	0.0038	mg/L	0.0093	0.4
IRON_LKE	Copper	0.0020	mg/L	0.0093	0.2
LIME_LKE	Copper	0.0024	mg/L	0.0093	0.3
WCOALLKE	Copper	0.0032	mg/L	0.0093	0.3
ECOALLKS	Copper	0.0023	mg/L	0.0093	0.2
IRON_LKS	Copper	0.0010	mg/L	0.0093	0.1
LIME_LKS	Copper	0.0010	mg/L	0.0093	0.1
WCOALLKS	Copper	0.0022	mg/L	0.0093	0.2
ECOALLKE	Copper, dissolved	0.0015	mg/L	0.0089	0.2
IRON_LKE	Copper, dissolved	0.0017	mg/L	0.0089	0.2
LIME_LKE	Copper, dissolved	0.0016	mg/L	0.0089	0.2

TABLE C1  
Complete Sample Data for Selected Sediment Chemical parameters

Sample ID	Analyte	Result	Units	Criteria	Analyte Result / Water Criteria Ratio
WCOALLKE	Copper, dissolved	0.0011	mg/L	0.0089	0.1
ECOALLKS	Copper, dissolved	0.00049	mg/L	0.0089	0.1
IRON_LKS	Copper, dissolved	0.00098	mg/L	0.0089	0.1
LIME_LKS	Copper, dissolved	0.0010	mg/L	0.0089	0.1
WCOALLKS	Copper, dissolved	0.00044	mg/L	0.0089	0.0
CLECV3-DS-1	Lead	6.54	mg/kg	35.8	0.2
CLECV3-DS-1-D	Lead	8.96	mg/kg	35.8	0.3
CLECV3-DS-1MS	Lead	8.12	mg/kg	35.8	na
CLECV3-DS-1SD	Lead	7.49	mg/kg	35.8	na
CLECV4-DS-1	Lead	9.99	mg/kg	35.8	0.3
DLHCV1-DS-1	Lead	1.89	mg/kg	35.8	0.1
DLHCV1-DS-1-D	Lead	2.21	mg/kg	35.8	0.1
DLHCV1-DS-1MS	Lead	2.85	mg/kg	35.8	na
DLHCV1-DS-1SD	Lead	2.92	mg/kg	35.8	na
DLHCV1-LS-1	Lead	0.0011	mg/L	0.0032	0.3
DLHCV1-LS-1-D	Lead	0.00091	mg/L	0.0032	0.3
DLHCV1-LS-1LR	Lead	1.1	µg/L	0.0032	0.3
DLHCV1-LS-1MS	Lead	18.2	µg/L	0.0032	na
DLHCV1-LS-1SD	Lead	18.1	µg/L	0.0032	na
DLHCV1-SS-1	Lead	11.4	mg/kg	35.8	0.3
DLHCV1-SS-1-D	Lead	237	mg/kg	35.8	6.6
DLHCV1-SS-1MS	Lead	203	mg/kg	35.8	na
DLHCV1-SS-2	Lead	91.6	mg/kg	35.8	2.6
DLHCV2-DS-1	Lead	5.48	mg/kg	35.8	0.2
DLHCV2-LS-1	Lead	0.0013	mg/L	0.0032	0.4
DLHCV2-SS-1	Lead	2.67	mg/kg	35.8	0.1
ECOALLKE	Lead	0.0019	mg/L	0.0032	0.6
IRON_LKE	Lead	0.00038	mg/L	0.0032	0.1
LIME_LKE	Lead	0.00045	mg/L	0.0032	0.1
WCOALLKE	Lead	0.00071	mg/L	0.0032	0.2
ECOALLKS	Lead	0.00087	mg/L	0.0032	0.3
IRON_LKS	Lead	0.000081	mg/L	0.0032	0.0
LIME_LKS	Lead	0.000047	mg/L	0.0032	0.0
WCOALLKS	Lead	0.00034	mg/L	0.0032	0.1
ECOALLKE	Lead, dissolved	0.000047	mg/L	0.0025	0.0
IRON_LKE	Lead, dissolved	0.000062	mg/L	0.0025	0.0

TABLE C1  
Complete Sample Data for Selected Sediment Chemical parameters

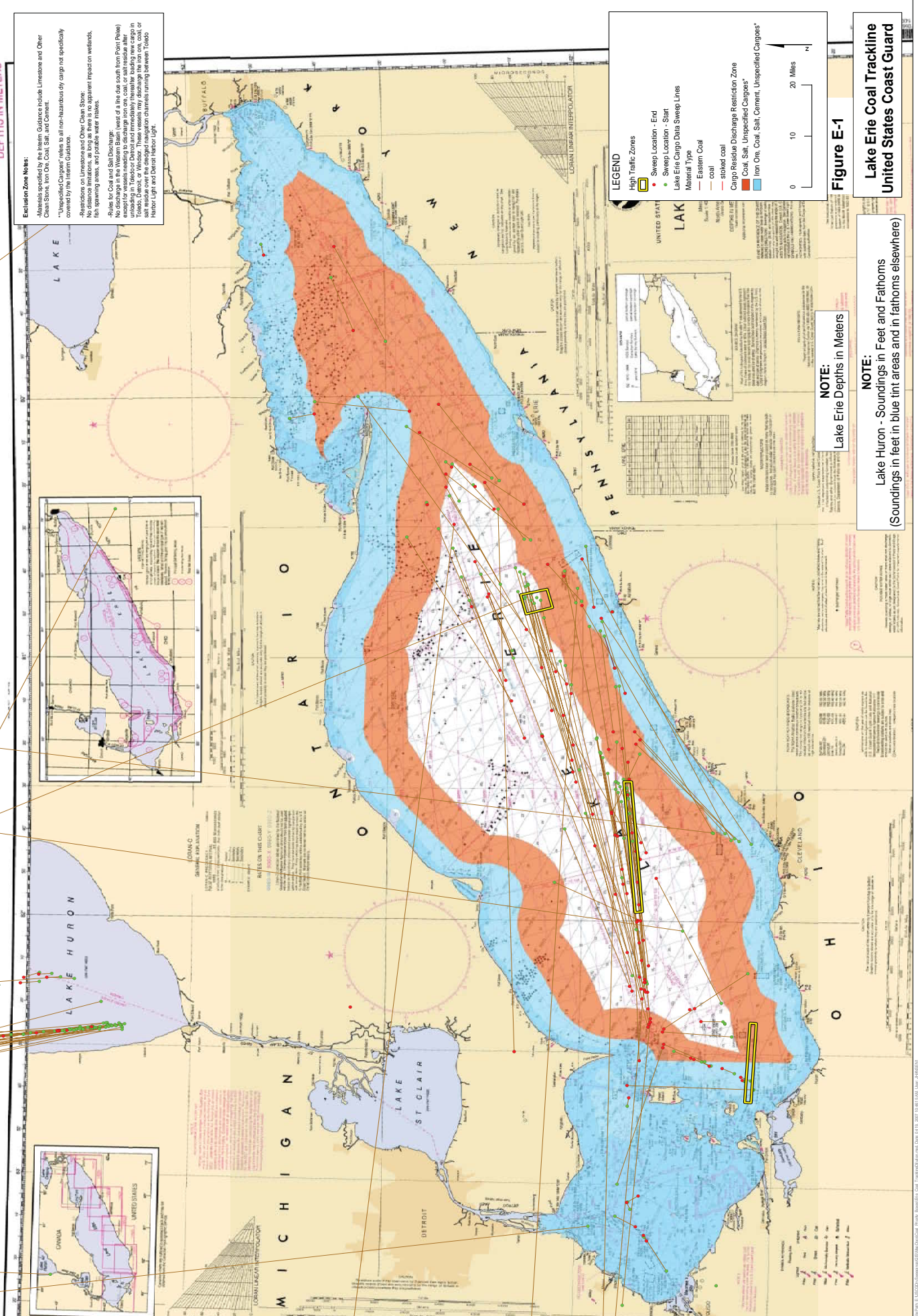
Sample ID	Analyte	Result	Units	Criteria	Analyte Result / Water Criteria Ratio
LIME_LKE	Lead, dissolved	0.000051	mg/L	0.0025	0.0
WCOALLKE	Lead, dissolved	0.000047	mg/L	0.0025	0.0
ECOALLKS	Lead, dissolved	0.000047	mg/L	0.0025	0.0
IRON_LKS	Lead, dissolved	0.000066	mg/L	0.0025	0.0
LIME_LKS	Lead, dissolved	0.000047	mg/L	0.0025	0.0
WCOALLKS	Lead, dissolved	0.000047	mg/L	0.0025	0.0
CLECV3-DS-1	Naphthalene	400	µg/kg	176	2.3
CLECV3-DS-1-D	Naphthalene	430	µg/kg	176	2.4
CLECV3-DS-1DL	Naphthalene	270	µg/kg	176	1.5
CLECV3-DS-1MS	Naphthalene	250	µg/kg	176	na
CLECV3-DS-1SD	Naphthalene	400	µg/kg	176	na
CLECV4-DS-1	Naphthalene	3100	µg/kg	176	17.6
DLHCV1-DS-1	Naphthalene	120	µg/kg	176	0.7
DLHCV1-DS-1-D	Naphthalene	150	µg/kg	176	0.9
DLHCV1-DS-1MS	Naphthalene	170	µg/kg	176	na
DLHCV1-DS-1SD	Naphthalene	150	µg/kg	176	na
DLHCV1-LS-1	Naphthalene	0.093	µg/L	12	0.0
DLHCV1-LS-1-D	Naphthalene	0.10	µg/L	12	0.0
DLHCV1-LS-1RE	Naphthalene	0.013	µg/L	12	0.0
DLHCV1-SS-1	Naphthalene	1.2	µg/kg	176	0.0
DLHCV1-SS-1-D	Naphthalene	44	µg/kg	176	0.3
DLHCV1-SS-1-DRE	Naphthalene	45	µg/kg	176	0.3
DLHCV1-SS-1MS	Naphthalene	25	µg/kg	176	na
DLHCV1-SS-1RE	Naphthalene	1.7	µg/kg	176	0.0
DLHCV1-SS-1SD	Naphthalene	30	µg/kg	176	na
DLHCV1-SS-2	Naphthalene	13	µg/kg	176	0.1
DLHCV2-DS-1	Naphthalene	360	µg/kg	176	2.0
DLHCV2-DS-1MS	Naphthalene	250	µg/kg	176	na
DLHCV2-DS-1SD	Naphthalene	280	µg/kg	176	na
DLHCV2-LS-1	Naphthalene	0.29	µg/L	12	0.0
DLHCV2-SS-1	Naphthalene	94	µg/kg	176	0.5
WCOALLKE	Naphthalene	0.051	µg/L	12	0.0
ECOALLKE	Naphthalene	0.29	µg/L	12	0.0
ECOALLKS	Naphthalene	0.26	µg/L	12	0.0
ECOALLKSRE	Naphthalene	0.26	µg/L	12	0.0
WCOALLKS	Naphthalene	0.030	µg/L	12	0.0

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## Appendix E Lake Figures

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**Exclusion Zone Notes:**

Materials specified by the Interim Guidance include Limestone and Other Clean Stone, Iron Ore, Coal, Salt, and Cement.  
"Unspecified Cargoes" refers to all non-hazardous dry cargo not specifically covered by the Interim Guidance.  
Residue on Limestone and Other Clean Stone: No discharge in the Western Basin (west of a line south from Point Pelee) except for vessels needing to discharge iron ore, coal, or salt residue after leaving the Western Basin. These vessels may discharge the iron ore, coal, or salt residue over the designated navigation channels running between Toledo Harbor Light and Detroit Harbor Light.

**LEGEND**

- High Traffic Zones
- Sweep Location - End
- Sweep Location - Start
- Lake Erie Cargo Data Sweep Lines
- Material Type
  - coal
  - Iron Ore, Coal, Salt, Cement, Unspecified Cargoes
- Carpo Residue Discharge Restriction Zone

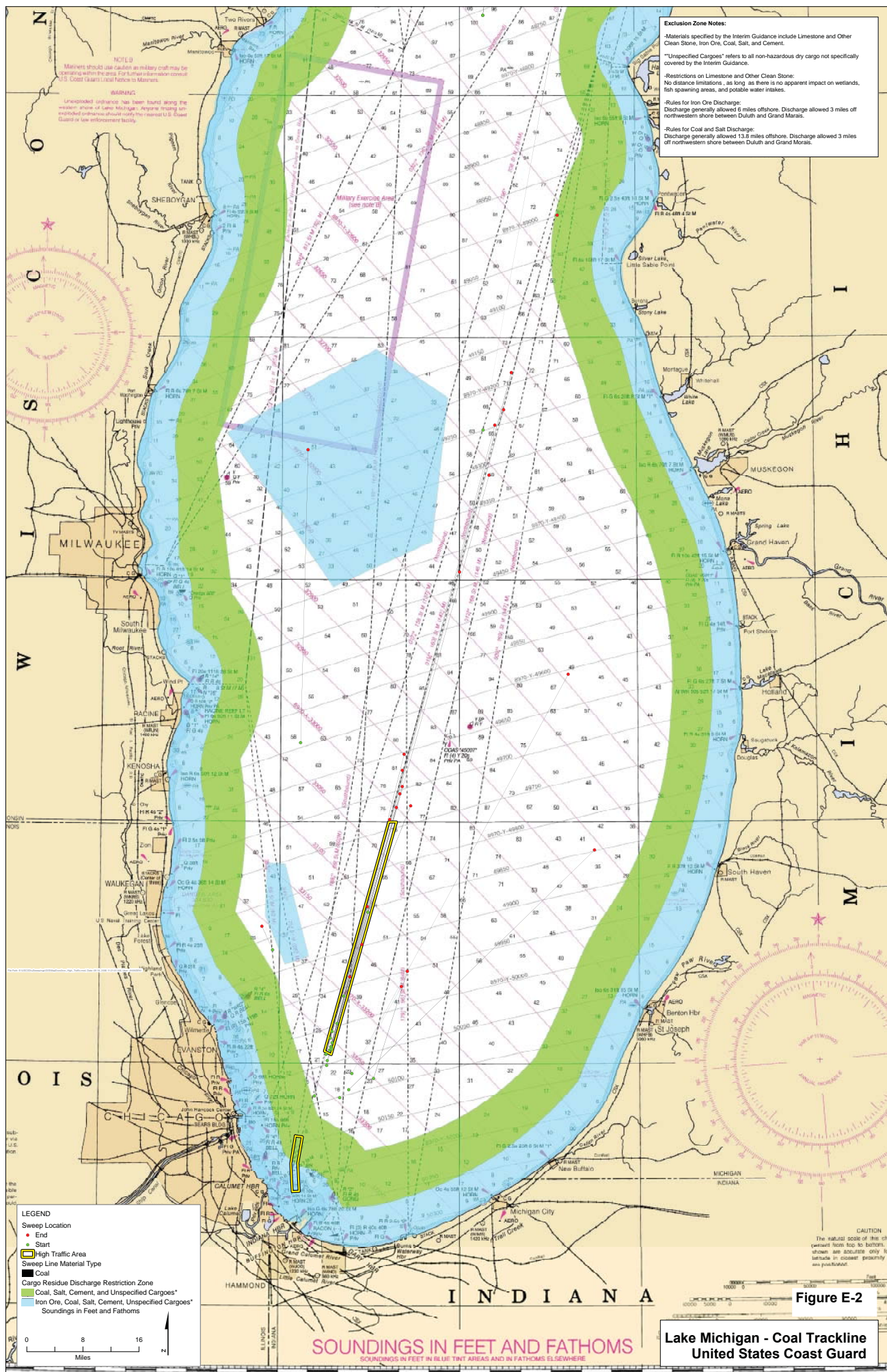


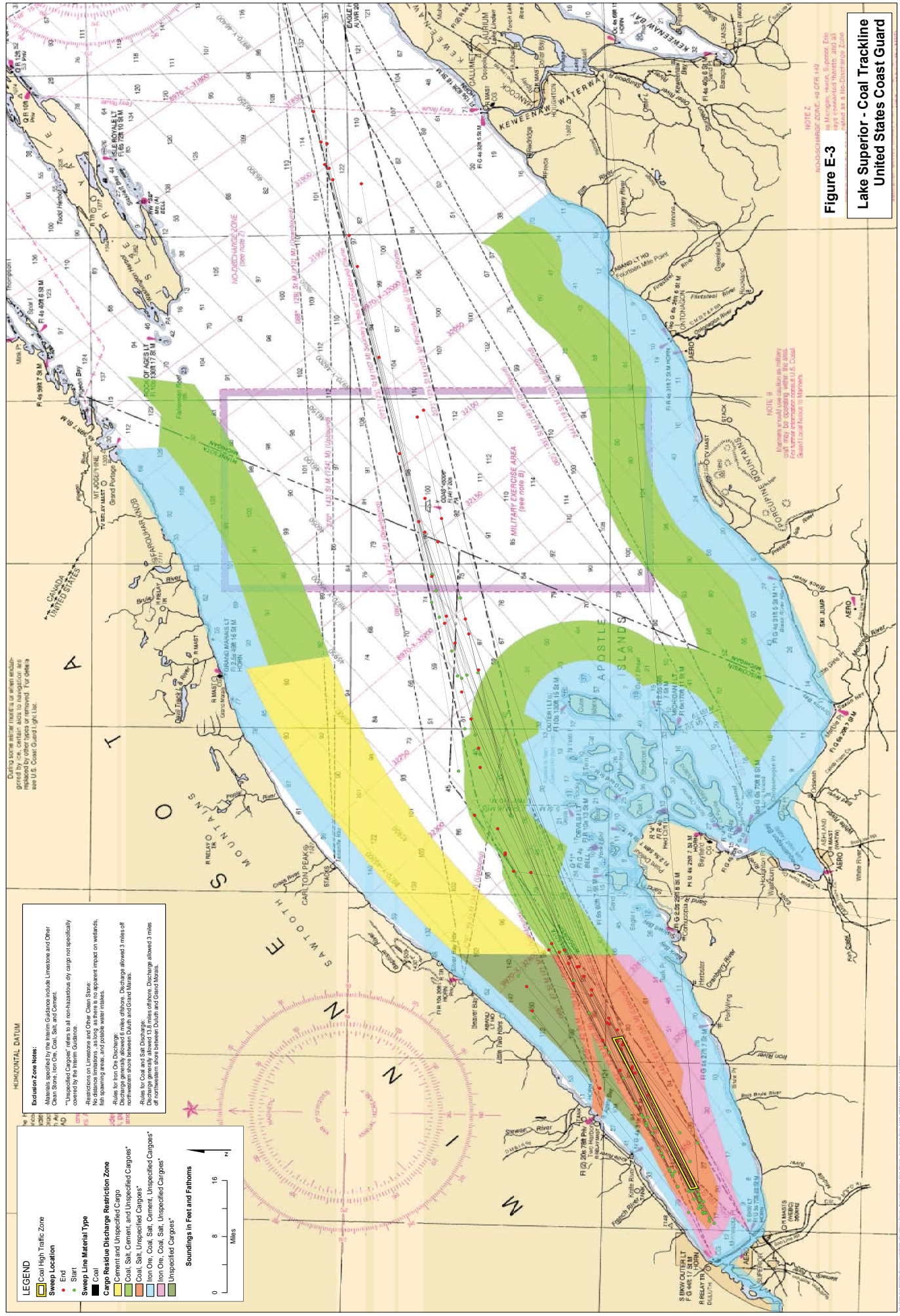
**Figure E-1**

**Lake Erie Coal Trackline  
United States Coast Guard**

**NOTE:**  
Lake Erie Depths in Meters

**NOTE:**  
Lake Huron - Soundings in Feet and Fathoms  
(Soundings in feet in blue tint areas and in fathoms elsewhere)





**Exclusion Zone Notes:**  
Materials specified by the Interim Guidance include Limestone and Other Clean Stone, Iron Ore, Coal, Salt, and Cement.  
"Unspecified Cargoes" refers to all non-hazardous dry cargo not specifically covered by the Interim Guidance.  
Restrictions on Limestone and Other Clean Stone:  
For distance limitations, as long as there is no apparent impact on wetlands, for distance limitations, as long as there is no apparent impact on wetlands, for distance limitations, as long as there is no apparent impact on wetlands.  
Rules for Dry Bulk Discharge:  
Discharge generally allowed 6 miles offshore. Discharge allowed 3 miles off northwest shore between Duluth and Grand Marais.  
Rules for Coal and Salt Discharge:  
Discharge generally allowed 13.5 miles offshore. Discharge allowed 3 miles off northwest shore between Duluth and Grand Marais.

**LEGEND**

- Coal High Traffic Zone
- Sweep Location
- Start
- End
- Sweep Line Material Type
- Coal
- Cement and Unspecified Cargo
- Coal, Salt, Cement, and Unspecified Cargoes
- Coal, Salt, Cement, and Unspecified Cargoes
- Iron Ore, Coal, Salt, Cement, Unspecified Cargoes
- Iron Ore, Coal, Salt, Cement, Unspecified Cargoes
- Unspecified Cargoes
- Soundings in Feet and Fathoms

0 8 16 Miles

**Figure E-3**  
**Lake Superior - Coal Trackline**  
**United States Coast Guard**

**NOTE 1**  
Interim guidance is advisory only. For current information consult U.S. Coast Guard Local Notice to Mariners.

**NOTE 2**  
This chart is not to be used as a guide to navigation.

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**Appendix F**  
**DCR Discharges Grain Size**  
**Distribution and Settling Velocities**

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# DCR Discharges Grain Size Distribution and Settling Velocities

Samples were collected from the decks and sumps of cargo vessels to determine the grain size distribution of DCR. Table E-1 lists the number of samples collected for each material. No samples were collected from a sump of a ship carrying eastern coal. The samples were averaged to obtain a representative grain size distribution. Settling velocities were calculated using classical discrete particle settling equations (including Stokes' equation), which apply to spherical particles (Table E-2; see next page). Actual settling velocities of DCR will likely be lower than indicated in Table E-2 because of particle irregularity. This analysis also neglected water currents and turbulence due to ships, wind, and density currents. These effects may further reduce settling velocity and serve to keep the particles suspended for longer periods of time.

The deck DCR contained much more fine material than the solids collected from the sumps. The western coal deck DCR samples had 55 percent of the total mass contained in particles smaller than 0.2 inches (0.6 mm) in diameter while the western coal sump solids had only 1 percent of total mass in particles smaller than 0.2 inches (0.6 mm) (Table E-2). This disparity could be partially due to sampling bias. The samples retrieved from the sumps were grab samples collected by scooping solids from the bottom of the sump. Additionally, some of the finer material was suspended in the in the sump liquid and may not have been collected with the larger solids (Table E-3).

TABLE E-1  
DCR Solids Sampled for Grain Size Analysis

Sample Description	No. of Samples Analyzed
Western Coal DS	2
Western Coal SS	3
Eastern Coal DS	2
Eastern Coal SS	0
Limestone DS	2
Limestone SS	3
Taconite DS	2
Taconite SS	4

DS – Deck DCR Discharges (Solids collected from the deck of the vessel)

SS – Sump Solids (Solids collected from the sump of the vessel)

TABLE E-3  
TSS Concentration in Sump Liquid

Sample Description	TSS (mg/L)
Western Coal #1	16.0
Western Coal #2	232
Limestone #1	406
Limestone #2	174
Taconite	9.2

TABLE E-2  
DCR Discharges: Average Grain Size Distribution and Particle Settling Velocities

Particle Diameter (mm)	Corresponding Soil Classification	Coal					Limestone				Taconite			
		Western Coal DS % Mass Fraction	Western Coal SS % Mass Fraction	Eastern Coal DS % Mass Fraction	Coal Settling Velocity (m/s)	Coal Time to Fall 100' (Minutes)	DS % Mass Fraction	SS % Mass Fraction	Settling Velocity (m/s)	Time to Fall 100' (Minutes)	DS % Mass Fraction	SS % Mass Fraction	Settling Velocity (m/s)	Time to Fall 100' (Minutes)
0.001–0.002	Clay	0.0	0.0	0.0	0.000000	1,827,548	3.0	0.0	0.000001	392,553	0.0	0.0	0.000001	350,752
0.002–0.005	Silt	0.0	0.0	0.0	0.000002	335,672	4.8	0.0	0.000007	72,102	0.0	0.6	0.000008	64,424
0.005–0.02	Silt	2.8	0.0	0.0	0.000019	26,317	11.0	0.3	0.0001	5,653	0.0	0.8	0.0001	5,051
0.02–0.05	Silt	2.8	0.0	0.0	0.0002	3,357	11.3	0.2	0.0007	721	0.0	4.0	0.0008	644
0.05–0.064	Silt	0.8	0.0	0.0	0.0004	1,266	4.0	0.0	0.0019	272	0.0	3.8	0.0021	243
0.064–0.075	Very fine sand	13.1	0.0	11.0	0.0006	851	2.7	20.4	0.0028	183	19.5	9.2	0.0031	163
0.075–0.15	Very fine sand	6.3	0.0	6.0	0.0016	325	8.2	4.3	0.01	69.8	1.3	3.3	0.01	62.4
0.15–0.3	Fine sand	14.8	0.2	11.9	0.01	81.2	8.8	1.0	0.02	22.3	7.9	3.4	0.03	20.1
0.3–0.6	Medium sand	14.2	0.8	21.7	0.02	27.7	9.1	1.0	0.06	7.9	42.1	4.7	0.07	7.2
0.6–1.18	Coarse sand	7.0	1.8	17.5	0.05	10.7	10.9	2.5	0.14	3.7	22.3	6.0	0.15	3.4
1.18–2.36	Very coarse sand	3.0	26.4	5.6	0.10	5.2	7.5	4.0	0.25	2.0	4.8	7.0	0.27	1.9
2.36–3.35	Granule	5.2	3.3	6.0	0.15	3.5	2.6	4.6	0.37	1.4	0.3	2.0	0.39	1.3
3.35–4.75	Pebble	5.5	5.8	5.8	0.20	2.5	4.6	4.6	0.44	1.2	1.4	2.9	0.47	1.1
4.75–19	Pebble	21.0	55.7	11.7	0.35	1.5	10.3	21.9	0.75	0.7	0.1	51.9	0.80	0.6
19–37.5	Pebble	3.4	5.1	2.4	0.54	0.9	0.0	31.8	1.16	0.4	0.0	0.1	1.23	0.4
37.5–75	Pebble	0.0	0.4	0.0	0.76	0.7	0.0	3.0	1.64	0.3	0.0	0.0	1.74	0.3

*Note:*  
DS – deck DCR discharges (solids collected from the deck of the vessel)  
SS – sump solids (solids collected from the sump of the vessel)  
Corresponding soil classification was included as a reference to more clearly illustrate the size of each particle fraction.  
Samples were not collected from sumps of vessels carrying eastern coal.  
Settling Velocity Assumptions:  
Water Temperature: 5° C; Density = 999.95 kg/m<sup>3</sup>; Viscosity = 0.001527 N·s/m<sup>2</sup>  
Specific Gravity: Coal: 1.4, Limestone: 2.6, Taconite: 2.8

Coal particles greater than 0.05 inches (1.18 mm) in diameter sink to the lake bottom relatively quickly (> 0.3 feet per second or 0.1 meters per second), whereas smaller particles take hours, even days, to settle (Table E-2). Almost all (97 percent by mass) of the western coal sump solids were greater than 0.05 inches (1.18 mm) in diameter, but only 38 percent of the mass of the western coal deck DCR were larger than 0.05 inches (1.18 mm). Eastern coal deck DCR sweepings were very similar, with 32 percent of the mass larger than 0.05 inches (1.18 mm). A significant portion of the mass of western and eastern coal deck DCR is fine material (0.064–1.18 mm). The slowest settling particles in this range require 14 hours to settle 100 feet (30.5 meters), whereas the fastest settling particles require 10 minutes.

Limestone deck DCR contains the finest material of all samples and thus remain suspended in the water column for a long period of time. About 34 percent of the mass of the limestone deck DCR does not reach a depth of 100 feet (30.5 meters) four hours after discharge.

The taconite sump solids contained a significant amount of fine particles. About 25 percent of the mass of the taconite sump solids was less than 0.01 inches (0.3 mm). This fine material requires at least 20 minutes to fall 100 feet (30.5 meters) through the water column. The finest of the material remain suspended for hours. The finest of the taconite sump solids (1.5 percent by mass) remains suspended for more than 3 days.

Table E-4 summarizes the average grain size distribution and particle settling velocities for coal, limestone, and taconite.

TABLE E-4  
Coal Sump Solids Averaged Grain Size Distribution

Corresponding Soil Classification Based on Particle Diameter	Particle Diameter (mm)	Settling Velocity (ft/s)	% Fraction by Mass
Fine sand	0.15–0.3	0.03	0.2
Medium sand	0.3–0.6	0.07	0.8
Coarse sand	0.6–1.18	0.18	1.8
Very coarse sand	1.18–2.36	0.35	26.4
Granule	2.36–3.35	0.50	3.3
Pebble	3.35–4.75	0.67	5.8
Pebble	4.75–19	1.15	55.7
Pebble	19–37.5	1.77	5.1
Pebble	37.5–75	2.50	0.4